Journal of Human Evolution 211 (2026) 103789

Contents lists available at ScienceDirect

Journal of Human Evolution

journal homepage: www.elsevier.com/locate/jhevol

The site of Notarchirico (Venosa Basin, Italy) and the hominin behavior in the Middle Pleistocene: New insights from taphonomy and spatial archaeology

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ARTICLE INFO

Article history:
Received 27 March 2025
Accepted 16 November 2025
Available online xxx

Keywords:
Homo heidelbergensis
Human paleoecology
Italian Peninsula
Lower Paleolithic
Zooarchaeology

ABSTRACT

The early Middle Pleistocene is characterized by a significant turnover in the fauna across Europe, creating new niches and new subsistence opportunities for hominin populations. Open-air sites provide a unique opportunity to study the distinct and effective resource acquisition strategies that were developed by hominins during this period. The archaeological site of Notarchirico (695–610 ka) is a key locality for the study of the behavior of hominin groups in the Italian Peninsula and Western Europe. The site is one of the few open-air sites to have yielded human remains, namely a femur fragment of *Homo heidelbergensis*, in such ancient chronologies. Notarchirico also yielded numerous lithic and faunal remains, although the latter, despite their abundance, have so far received scarce attention from a taphonomic perspective. Here we present a study of the site, including material from both ancient and modern collections. Spatial and taphonomic inferences can be drawn about the formation of the assemblages, as well as behavioral inferences about the Middle Pleistocene hominin populations. Despite the poor preservation of the bones, the data suggest that both hominins and carnivores foraged in the area. From a taphonomic perspective, spatial analyses suggest that water flows may have altered the association between osteological and lithic assemblages. There is compelling evidence that suggests that hominin groups inhabited the area surrounding the site for a minimum of 100 ka as the region was abundant in resources. Notarchirico is a pivotal site for understanding the adaptation of hominins and their interaction with the Middle Pleistocene ecosystems.
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1. Introduction

Pleistocene fossil concentrations have a greater possibility of being well preserved in closed sedimentary environments, such as caves or rock shelters (Butzer, 1982), in contrast to open sedimentary environments, because remains deposited under the cover provided by caves or rocky walls are better protected from weathering processes before, during, and after their burial (Brain, 1981; Capaldo, 1998). For this reason, fossil concentrations in open-air settings have neither received the same level of attention historically nor included in contemporary research. Studies conducted by researchers such as Behrensmeyer (1975, 1978, 1983) or Hill (1979a, 1979b) in the African savanna have demonstrated that such concentrations are extremely valuable for

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https://doi.org/10.1016/j.jhevol.2025.103789
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reconstructing the paleoecological dynamics of Pleistocene hominins while also positioning the savanna as a first-rate referential framework. Until that moment, research on many excavated open-air sites had primarily focused on stone-tool assemblages as these nonabiotic remains were not typically affected by the same processes operating in open-air contexts and had received most of the attention (Binford, 1983). In open-air contexts, the material tends to dispersion naturally, rather than accumulation, meaning that osteological fossil concentrations must result from dynamic processes that transport and deposit elements in the same location (Domínguez-Rodrigo and de la Torre, 1999). These agents include biological factors, such as hominins or carnivores, as well as physical processes, such as water currents or alluvial deposits (e.g., Leakey, 1971; Isaac, 1978; Brain, 1981; Binford, 1981, 1983; Domínguez-Rodrigo and de la Torre, 1999; Domínguez-Rodrigo et al., 2002, 2018, 2024; Yravedra and Linares-Matás, 2024), which may act either independently or in combination to form these accumulations.

The presence of concentrations of stone-tool faunal remains in open-air Pleistocene deposits enables behavioral inferences to be made about the different activities carried out by Pleistocene hominin groups in this type of landscapes, and consequently, this information can be used to make inferences about the types of occupations (Leakey, 1971; Isaac, 1978; Isaac and Crader, 1981). Leakey (1971) proposed a classification of the Olduvai Gorge open-air assemblages based on the different types of occupations, differentiating between a) living floors, b) butchering or kill sites, c) sites in fluvial contexts, and d) vertical scatter deposits. The differentiation of these types of sites is based on the presence, absence, or co-occurrence of lithic and faunal remains, as well as by the different types of relationship between all these elements.

The identification of living floors in open-air sites is particularly challenging as hominin groups typically established their home bases in cavities or rock shelters (Binford, 1983). These accumulations are distinguished by the presence of stone tools and faunal remains and, at the taphonomic level, manifest signals of carcass anthropization. They have been documented in the archaeological record at FLK 22 (Domínguez-Rodrigo et al., 2002) and DS (Domínguez-Rodrigo et al., 2017) from Olduvai.

Conversely, the kill/butchering sites are defined as locations where substantial quantities of meat were acquired. Kill sites are defined by the presence of lithic remains alongside those of ungulates, suggesting the occurrence of hunting activities within these locations, such as what has been documented in Schöningen (Voormolen, 2008), Ambrona (Moclán, 2023), Cuesta de la Bajada (Domínguez-Rodrigo et al., 2015; Moclán, 2023), and Gran Dolina TD10.2 (Rodríguez-Hidalgo et al., 2017; Arteaga-Brieba et al., 2023) sites. On the other hand, in the butchering sites, the stone tools are spatially associated with the carcass of a single megamammal, such as those described in the hippopotamus/artifact site locality of Koobi Fora in Kenya (Isaac, 1971; Isaac and Crader, 1981), in ST4 (Peninj) (Domínguez-Rodrigo et al., 2002) or in the Pit 1 of the Barranc de la Boella (Mosquera et al., 2015).

These types of assemblages provide detailed insights into the daily life of Pleistocene hominin populations. However, some open-air archaeological assemblages, especially in fluvial or deltaic contexts, are not the result of specific activities but may reflect more discrete resource-foraging activities or leave a lesser imprint on the archaeological record (Pineda and Saladié, 2022), sometimes as vertical deposits in which the lithic and faunal assemblages composing them are not related or where this relationship cannot be proven (Leakey, 1971; Isaac, 1971). In this sense, many of the assemblages excavated in Olduvai Gorge in the second half of the 20th century have now been reconsidered as vertical palimpsests in which anthropogenic activity is marginal (e.g., Egeland et al., 2004; Domínguez-Rodrigo et al., 2007; Akuku et al., 2022) in the same line as the origin of the paradigmatic site of Torralba were reconsidered (Pineda and Saladié, 2019). More recently, these interpretations have been developed at the Early Pleistocene site of Barranc de la Boella, where, beyond the aforementioned butchery site of Pit 1, the other excavated pits, named La Mina and El Forn, have been described as sites of transit, where early hominin groups would have carried out foraging activities not necessarily related to the exploitation of animal resources (Pineda et al., 2015, 2017; Pineda and Saladié, 2022).

Focusing on the Italian Peninsula, numerous Middle Pleistocene sites were discovered and excavated throughout the 20th century, especially during its second half. Research at these sites was conducted with the aim to collect new archaeological and paleontological material. Several studies were mainly concentrated on lithic remains and the implications of their study for understanding human occupations in Europe, as seen in cases such as Isernia La Pineta, Notarchirico, or Loreto (Coltorti et al., 1981; Cremaschi, 1983; Cremaschi and Peretto, 1988; Ancontani et al., 1992; Piperno, 1999). Although paleoanthropologic (Belli et al., 1991) or faunal studies were occasionally conducted, they had always been approached from a paleontological and evolutionary perspective (e.g., Sala, 1983, 1996, 1999; Anconetani et al., 1992; Cassoli et al., 1999; Piperno, 1999), and those related with hominin behavior were scarce (Cassoli et al., 1993). The recent study of level 3col of Isernia La Pineta (Pineda et al., 2020) has focused on taphonomic inferences that allow us to rule out a main role of hominins in the formation of the assemblage, in which the evidence of their activity would also be linked to foraging resources that the landscape could provide them with.

The beginning of Middle Pleistocene is placed at the Matuyama/Brunhes paleomagnetic reversal (c. 0.78 Ma, within the Marine Isotope Stage [MIS] 19). The Middle Pleistocene in Europe is characterized by multiple faunal exchanges that are mainly controlled by climatic oscillations (Strani et al., 2019). The first occurrence in Europe of the steppe mammoth *Mammuthus trogontherii* and of the red deer *Cervus elaphus acoronatus* have been considered as bioevents characterizing the oldest early Middle Pleistocene faunas (Galerian), although the typical Galerian fauna starts spreading over Europe during the latest Early Pleistocene, leading to new adaptations and dispersals, in particular among the ungulates (Gliozzi et al., 1997; Mecozzi et al., 2021b, 2023, 2024a). Significant megafauna species such as *Mammuthus meridionalis* and *Pachycrocuta brevirostris* disappeared (Iannucci et al., 2021; Sardella and Strani, 2025; with references therein), while predators including *Homotherium latidens* experienced a marked decline in their population levels across Europe and Italian peninsula (Sardella and Iurino, 2012).

Among carnivores, the giant short-faced hyaena *Pac. brevirostris* became extinct at the beginning of Middle Pleistocene and was ecologically replaced by the spotted hyaena *Crocuta* (Sardella and Petrucci, 2012; Iannucci et al., 2021). Lion and leopard were widespread, and the large felid *Panthera gombaszoegensis* became extinct during this period (Sardella and Strani, 2025; Iannucci et al., 2024). Canids are represented by the middle-sized wolf *Canis mosbachensis*, the hunting dog *Xenocyon lycaonoides*, and the dhole *Cuon priscus*. The first occurrence of the 'modern' wolf *Canis lupus* is recorded at Ponte Galeria around 0.4 Ma (Mecozzi et al., 2021b; Iurino et al., 2022). *Mammuthus trogontherii* and the straight-tusked elephant *Palaeoloxodon antiquus* characterize different faunal assemblages of the early Middle Pleistocene, surviving until the end of the Middle Pleistocene and the earliest Late Pleistocene, respectively (Mecozzi et al., 2021c; Sardella and Strani, 2025).

This faunal renewal resulted in an increase in available resources for human groups, whose activities included hunting and opportunistic scavenging. In this sense, and as heirs to the evidence from the Early Pleistocene, kill sites and natural traps continue to be present, with evidence of human hunting, such as sublevel TD10.2 Gran Dolina (Sierra de Atapuerca). This site has been interpreted as a place where the communal hunting of bison may have been conducted as early as 400 ka (Rodríguez-Hidalgo et al., 2017). This is comparable to the aforementioned Schöningen site, where evidence of communal and specialized horse hunting has been found, using spears and javelins (Voormolen, 2008). Those represent the oldest evidence of communal hunting strategies, suggesting access to large quantities of meat by Middle Pleistocene hominin groups. It is also from this point onward that the identification in the archaeological record of caves occupied as habitats seems to be more abundant, with hunting standing out as the main subsistence strategy. Representative examples include La Caune de l'Aragó (Chen and Moigné, 2018), Orgnac 3 (Moncel et al., 2005, 2012), Abri du Payre (Moncel et al., 2007), Bilzingsleben (Mania and Mania, 2005), Cueva del Ángel (Botella et al., 2006; Barroso Ruiz et al., 2011), Gran Dolina (Rodríguez-Hidalgo et al., 2015), and Bolomor Cave (Blasco and Fernández-Peris, 2009; Blasco et al., 2013).

Conversely, the information available on open-air sites is more limited and fragmented. Anthropic accumulations have been identified in this type of environment during the Middle Pleistocene, as evidenced by the aforementioned Cuesta de la Bajada (Moclán, 2023) and Terra Amata (Valensi et al., 2011). However, the role of hominins in many of these assemblages remains minimal or challenging to ascertain. In this study, we present the first taphonomic review of the unstudied levels (level B and below) of the Middle Pleistocene site of Notarchirico, both belonging to the ancient and modern collections. The main objective of this work is to characterize the hominin role and other agents and processes in the formation of the different levels and to infer the activities carried out by the hominin groups that inhabited the Venosa Basin at the early Middle Pleistocene.

2. The Venosa Basin and the site of Notarchirico

The Venosa Basin is a key region for the study of human evolution and ecological dynamics during the early Middle Pleistocene (700 ka and 500 ka), hosting numerous archaeological and paleontological sites within extensive sedimentary sequences deposited simultaneously with the eruptive activity of the Vulture stratovolcano (Raynal et al., 1990; Lefèvre et al., 2010; Pereira et al., 2015; Moncel et al., 2020). The potential of the area has been known since the beginning of the 20th century, with the discovery or excavation of some sites such as Loreto, Terranera, or Notarchirico (Piperno, 1999).

The first works in the Notarchirico area (Fig. 1A), recently synthetized by Mecozzi and colleagues (2024b), were coordinated by Virginia Ginetta Chiappella in 1956. Chiappella carried out a stratigraphic survey by means of a borehole, the location of which is currently unknown, discovering a rich archaeological and paleontological record (Piperno, 1999). However, systematic work on the present-day site of Notarchirico began in 1979, following a survey carried out by the Italian Institute of Human Palaeontology (Piperno and Segre, 1982; Piperno, 1999).

The first three excavation campaigns at Notarchirico took place in 1980, 1981, and 1984, covering 156 m^2 in the area known as '*scavo esterno*' (external excavation area, referring to the outside of the building that was constructed to house and display the paleosurfaces excavated from 1985 onward). From 1985 onward, the fieldwork focused on two areas known as '*scavo interno*' 1 and 2 (internal excavation area, referring to the interior of the building) (Fig. 1B). The excavation was carried out until 1995 and led to the discovery of 11 archaeological levels in a 7-m-deep sequence, from the upper level, known as 'Sopra α' (above α), to the lower level of that time, known as G. The extent of the excavated areas varies

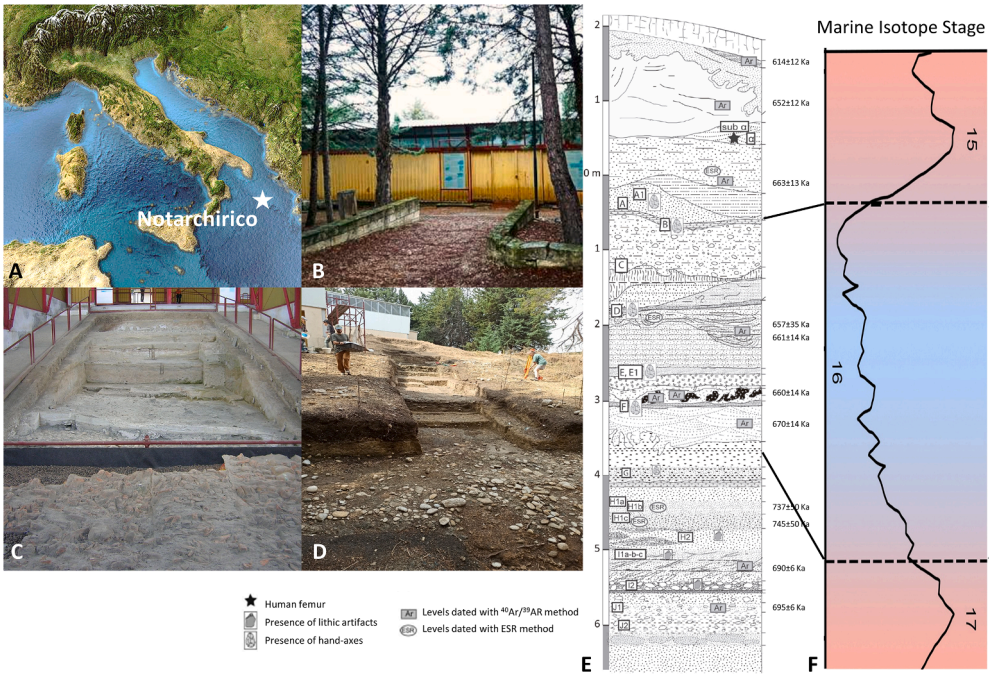

Figure 1. The site of Notarchirico. A) Notarchirico in the context of the Italian Peninsula; B) building containing the paleosurfaces excavated during the '80s and '90s; C) paleosurfaces excavated under the direction of M. Piperno; D) new trench excavated since 2016 under the direction of M.H. Moncel; E) stratigraphic succession of Notarchirico (modified from Mecozzi et al. (2024b)). F) Correlation of the Marine Isotope Stage curve with the stratigraphic succession of Notarchirico (modified from Mecozzi et al. (2024b)). Images allowed by the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

between 133 and 19 m^2, depending on the different archaeological levels and paleosurfaces (Fig. 1C). The archaeosurfaces consist of more or less dense beds of limestone pebbles, secondary quartz, and quartzite, corresponding to lacustrine remains (Moncel et al., 2020).

In 1990, a lateral discontinuity of 24 m^2 was documented in the upper part of the site sequence, at the contact between levels A and B. This area, called the '*elephant butchery area*,' was described as a special preserved context in which a new sublevel, called A1, was identified (Cassoli et al., 1993; Lefèvre et al., 1994; Piperno and Tagliacozzo, 2001). Elephant remains and stone tools were found, and the initial interpretations suggested that hominins may have consumed the soft parts of the elephant cranial skeleton, such as the brain, tongue, and proboscis (Cassoli et al., 1993; Piperno, 1999; Piperno and Tagliacozzo, 2001), although a recent re-evaluation of these assemblages has suggested that there is no relationship between the stone tools and the elephant remains, probably deposited in different events and with no evidence of relationship between them (Pineda et al., 2024).

Since 2016, new excavations have been carried out outside the building, on the hillside; starting from level F, a long trench of more than 30 m^2 has been opened, revealing a series of levels, named F, G, H, I1, and I2, with faunal and lithic remains (Fig. 1D), as well as the lowest level, named J, in which few remains were also recovered but probably not in situ. The archaeological record recovered at Notarchirico is extensive and includes a fragment of human femur attributed to *Homo heidelbergensis* and a rich faunal and lithic sample (e.g., Cassoli et al., 1999; Piperno, 1999; Pereira et al., 2015; Moncel et al., 2019, 2020, 2023; Santagata et al., 2020; Mecozzi et al., 2021a, 2024b; Carpentieri et al., 2023; Iannucci et al., 2024; Micarelli et al., 2024; Pineda et al., 2024).

2.1. Chronostratigraphic and paleoecological data

The Notarchirico sedimentary succession (Fig. 1E) consists of volcanoclastic sediments from the Vulture stratovolcano reworked by the alluvial environment (see Pereria et al., 2015; Mecozzi et al., 2024b: Table 1 for detailed descriptions). Each deposit corresponds to relatively short periods of accumulation and re-equilibration after volcanic inputs and before the passage of animals and hominins. Some levels (A, B, C, D, F, and I2) could be defined as dense accumulations of pebbles and cobbles, remains of lacustrine shore pavements, including material on and within the pavement (archaeosurfaces). The other levels record material between embedded pebbles and coarse deposits or sandy and clayey sediments filling water channels (levels H and E). The sediments overlying the pebbles often testify to low-energy fluvial sedimentation and regular inputs of volcanic material (Mecozzi et al., 2024b). New dating series have been carried out for the Notarchirico stratigraphic sequence, including both the sequence excavated at the end of the 20th century (levels above α to G) and the modern trench (levels F to I2) by electron spin resonance, $^{40}Ar/^{39}Ar$, and biochronology. These dates place Notarchirico in the early Middle Pleistocene. The age range obtained for the excavation paleosurfaces (levels G to α) is between 670 ± 4 ka and 614 ± 12 ka, placing them across the fully glaciated stage of MIS 16 and the beginning of MIS 15 interglacial. The $^{40}Ar/^{39}Ar$ dates on the bottom levels of the sequence excavated since 2016 provide ages between 695 and 670 ka. Thus, the bottom of the sequence corresponds paleoclimatically to the end of MIS 17 (Pereira et al., 2015; Moncel et al., 2020; Mecozzi et al., 2024b).

A comprehensive delineation of the stratigraphy and the chronological framework is provided by Mecozzi et al. (2024b) and can be summarized as follows:

- Level α: This level corresponds to archaeosurface α, which is formed by sandy and clayey deposits and is characterized by approximately 50 cm of reworked tephras.
- Levels A–A1–B: This sequence includes archaeosurface B, which features a pavement of pebbles. The subunit A1, identified in the '*elephant butchery area*,' consists of volcanic sands.
- Level C: It is characterized by a brown clayey deposit with a pavement of pebbles, in which the archaeosurface C is documented. The estimated thickness of this level is approximately 30 cm.
- Level D: The composition of this level consists of volcanic sands interbedded with clayey layers and carbonate. This level also comprises coarser sediments, which form the basis of archaeosurface D, which has been dated at 661 ± 4 ka.
- Level E: It is characterized by the presence of volcanic sands that contain carbonates and reworked tephras. Archaeosurface E is distinguished by the presence of diminutive pebbles.
- Level F: It includes cross-bedded volcanic and nonvolcanic sands with a thickness of approximately 20 cm. The archaeosurface F is constituted of a pavement of pebbles within black volcanic sands.
- Level G: It is distinguished by the presence of brown sediments, comprising small gravel, overlaid by dark-gray volcanic sands. This level encompasses archaeosurface G, which is approximately 30 cm in thickness.
- Level H: It features a silty-sandy deposit that is more oxidized and sandier in parts, with a few microbeds of dark minerals. The archaeological material is dispersed.
- Level I: It is comprised of two clearly differentiated sublevels, I1 and I2. I1 contains dispersed archaeological material. In contrast, I2 corresponds to a dense accumulation of cobbles and smaller elements, including limestone pebbles (Supplementary Online Material [SOM] Fig. S1), fine-grained sandstone cobbles, and flint nodules, within a 10- to 15-cm-thick layer.
- Level J: This unexcavated level consists of cobbles embedded in a clayish, volcano-derived matrix with a thickness of approximately 30 cm.

Recently, paleontological and paleoecological proxies have revealed the presence of three different mammal complexes in the Notarchirico sequence, documenting faunal dynamics in response to climate-driven changes recognized during the early Middle Pleistocene. The lower complex (levels I2 to G) shows the predominance of forested areas and scattered steppes and the

Table 1
Distribution of the faunal remains studied among the different levels and sublevels.

Level	Sublevel	Remains (n) from ancient collections	Remains (n) from modern collections
B	–	48	–
B/C	–	10	–
C	–	61	–
C/D	–	1	–
D	–	**113***	–
E	Sopra E	**179***	–
	1	84	–
E/F	–	–	134
F	–	9	**315***
G	Sopra G	21	–
	–	–	**417***
H	–	–	83
I	1	**207***	**1587***
	2	37	**541***
Total		**770**	**3077**

The levels in bold and marked with an asterisk (*) are those that contain a sufficient number of remains to allow for taphonomic inferences.

existence of water bodies (lakes or ponds), probably as a result of the deterioration of the fully interglacial conditions documented at the end of MIS 17; the middle complex (levels G to C), poor in mammalian remains, may be related to the glacial conditions of MIS 16; finally, the upper complex (levels B to above α) indicates an improved climate, in transition to the fully interglacial conditions of MIS 15 (Mecozzi et al., 2024b).

2.2. Archaeological and taphonomic context

The site of Notarchirico features one of the richest lithic corpora of the early Middle Pleistocene, comprehending around 2000 lithic artefacts across 13 archaeological layers (α, A, A1, B, C, D, E, E1, F, G, H, I1, and I2; Piperno, 1999; Moncel et al., 2020). The lithic assemblage is realized on local raw materials collected in secondary deposits (fluvial and lacustrine) including several lithologies of chert (flysch, nodular, and radiolarite), limestone, marl, and sandstone (Moncel et al., 2023). Hominins produced cores, flakes, retouched flakes, retouched nodules, pebble tools (chopper, rabot, unifacial tool, bifacial tool, etc.), large cutting tools, and bifaces (Santagata, 2016; Moncel et al., 2019, 2020, p. 202; Carpentieri et al., 2023; Rineau et al., 2023). Chert was mostly exploited for debitage (small nodules) and rarely for biface production, while limestone, sandstone, and marl were selected to obtain pebble tools and, more rarely, large-sized flakes. Analyses of cores and flakes indicate short and simple reduction sequences with scarce evidence of discoidal-type cores, sporadically attested in the top layers by a few pieces. The retouched tools (flakes and nodules) are relatively frequent, showing different morphologies such as scrapers, denticulates, notches, becs, and pointed implements. Bifaces are attested from layer G (680 ka), representing one of the earliest evidence of the Acheulean in Western Europe (Moncel et al., 2020), and then are alternatively documented in the uppermost levels of the sequence.

Regarding taphonomic and zooarchaeological inferences, those studies had focused on the upper levels of the sequence (above α, α, A, and A1), results of which showed minimal anthropogenic modifications on the bones, attributed, at least in part, as consequence of the poor preservation of the bone surfaces (Piperno, 1999). The only exception was the previously mentioned '*elephant butchery area*,' described as an event in which hominins exploited the elephant carcass (Cassoli et al., 1993; Piperno, 1999; Piperno and Tagliacozzo, 2001). This event represented one of the main pieces of evidence for carnivorism and megamammal exploitation in the early Middle Pleistocene in Western Europe. However, as previously mentioned, this association between fauna and stone tools has recently been questioned, and the latest studies suggest it might not have been a butchery area for this megaherbivore (Pineda et al., 2024).

3. Materials and methods

3.1. Materials

The materials included in the present work are 3847 macromammal remains from the level I2 to level B of Notarchirico, both belonging to the ancient (1980–1995) and modern (2016–2024) fieldwork campaigns (Table 1). These are the faunal materials that have not yet been subjected to taphonomic analysis as the materials from the top of the sequence (levels A and α) were studied by Piperno (1999) and those from the so-called '*elephant butchery area*' have been analyzed by Piperno and Tagliacozzo (2001) and recently re-examined by Pineda et al. (2024).

Some materials from both ancient and modern collections come from the same levels (F, G, I1, and I2), although from different paleosurfaces or pits. This is the case for materials from levels F and G, some of which come from the bottom of the ancient paleosurfaces but have also been recovered at the top of the modern trench. A little bit different is the case of remains from levels I1 and I2. Ancient materials from these levels come from some boreholes made by Piperno and his team, whose precise location is still unknown, whereas modern materials come from the new trench opened in 2016. As in all cases, the ancient and modern materials belonging to the same level come from different, unconnected pits, and they have been treated separately.

Remains from ancient excavation ($n = 770$) are housed in the *Museo Archeologico Nazionale di Venosa 'Mario Torelli'* and the *Parco Archaeologico di Notarchirico* (Venosa, Italy), as well as the *Museo delle Civiltà* (Rome, Italy), while those from modern excavations ($n = 3077$) are all temporally hosted in the *Museo Archeologico Nazionale di Venosa 'Mario Torelli.'* All materials included in this study underwent anatomical, taxonomic, and taphonomic analyses. However, the distribution of materials across the different sublevels is very uneven, especially in the levels excavated by Piperno. This is because parts of these levels were not excavated but were left exposed in situ on the paleosurfaces of the archaeological park. The low number of remains represents a limitation when making taphonomic inferences, so the taphonomic data present here will focus on the levels including a greater number of faunal remains: D, Sopra E, and I1 from the ancient excavations and F, G, I1, and I2 from the modern ones.

3.2. Methods

Taphonomic analysis All remains larger than 2 cm were analyzed, including all spatially recorded specimens. Remains smaller than 2 cm were not spatially recorded during the fieldwork and were grouped into level bags (organized by square and level). These bags were later reviewed, and remains suitable for study were included. The smaller remains were neither individualized nor included due to the limited information they provide. The remains were identified both anatomically and taxonomically. When identification was not possible, the unidentified remains were grouped by bone type and weight category, in accordance with the categories established by Saladié et al. (2011), which were based on the proposal established by Bunn (1982) for African assemblages. Weight-size categories were classified as follows: (1) very small size or size class 1, including 1a and 1b (<30 kg); (2) size class 2 (30–100 kg); (3) medium size or size class 3, including 3a and 3b (100–300 kg); (4) large size or size class 4 (300–1000 kg); and (5) very large size or size classes 5 and 6 (>1000 kg). Bone types were classified as long, flat, or irregular. The grade of eruption and wear of teeth (Hillson, 1996; Bunn and Pickering, 2010) and the grade of epiphyzation of bones were employed to elaborate the mortality age profiles (young, adult, and old). Quantification includes the number of specimens, number of identified specimens (NISP), the minimum number of elements (MNE), the minimum number of individuals, and the minimal animal unit (%MAU) (Binford, 1981; Brain, 1981; Lyman, 1994). Reference data were extracted from Lam et al. (1999) for large (*Equus* sp.) and medium (*Ce. elaphus*) sizes and from Lyman (1994) for small (*Ovis* sp.) sizes. Minimal animal unit was correlated to the bone mineral density in order to evaluate the relationship between the different anatomical elements and portions recovered and their mineral density. The fragmentation index of the length and cross section of the limb bones was calculated and the fracture edges of limb bones were analyzed in keeping with Bunn (1983) and Villa and Mahieu (1991) to stablish the state of bone (fresh or green) when fractured.

Bones were classified according to how much of their cortical surface is well preserved: good (>2/3), moderate (between 1/3 and

2/3), or poor (<1/3). Anthropic percussion has been analyzed according to Blumenschine and Selvaggio (1988). Carnivore activity documented on bones and bone surfaces was analyzed and described (Bonnichsen, 1973; Haynes, 1980, 1983; Maguire et al., 1980; Binford, 1981; Brain, 1981; Horwitz and Smith, 1988; Blumenschine, 1995). Carnivore modifications documented include tooth marks (pits and scores), furrowing, scooping out, shaft cylinders, digestion, crenulated edges, and serrated edges. Furrowing has been established in three different degrees, low, moderate, and high, according to Saladié et al. (2013).

Other taphonomic modifications, both biostratinomic and diagenetic, were also documented. Weathering and water abrasion were analyzed according to the grades established by Behrensmeyer (1978) and Cáceres (2002), respectively. The presence of other modifications (trampling, oxidation, corrosion or dissolution of surfaces, cementations, gnawing, root etching, and cracks by the pressure of sediments) was recorded in terms of presence/absence (Brain, 1981; Shipman, 1981; Fiorillo, 1987; Haynes, 1991; Fernández-Jalvo, 1992; Lyman, 1994).

Estimation of the skeletal profile has been employed for studying the level of competition among predators and the degree of ravaging in the modern collections of Notarchirico because there are not enough remains and associated elements from the ancient ones to make such estimations possible. The (NISP) epiphysis-to-shaft ratio (Blumenschine and Marean, 1993; Domínguez-Rodrigo et al., 2002) and the (MNE) axial-to-limb and proximal humerus + distal radio-to-distal humerus + proximal radio (Domínguez-Rodrigo and Organista, 2007) ratios were estimated to evaluate the different preservation of elements and portions. The theoretical method of Domínguez-Rodrigo and Organista (2007) and Egeland (2008) was used to measure competition among predators and their possible pressure in the landscape based on the relationships between the axial-to-limb and the proximal humerus + distal radio-to-distal humerus + proximal radio ratios and the epiphysis-to-shaft and the axial-to-limb ratios, respectively. Based on the methods of Faith and Behrensmeyer (2006) and Faith et al. (2007), the %MAU of limb ends was correlated with mineral density to infer competition levels in the ecological contexts of the different assemblages. For the correlation, Kendall's tau for nonparametric variables was employed. The percentage of change was calculated based on the method of Marean and Spencer (1991) and modified by Domínguez-Rodrigo et al. (2002) to gain insights into the epiphysis destruction process. The MNE of limb bones was calculated for each portion (following Faith et al., 2007: 2032), including diaphyses, which were the most represented limb bone elements.

The classification made by Voorhies (1969) of skeletal elements into groups to evaluate the effects of water transport and dispersion, based on the physical characteristics (size, density, and shape) of the bones for their scattering, has been applied. The integrity of the osteological sample and the effect of water current were also evaluated by classifying it according to the bone shape and structure, following the method of Domínguez-Rodrigo et al. (2018). Bones classified according to the structure were divided into cancellous, cortical, or mixed categories, whereas bones classified according to the shape were divided into flat bones (shaft fragments, ribs, scapulae, and mandibular fragments), cube-shaped specimens (vertebrae, carpal, and tarsal bones), and tube-shaped bones (specimens mainly formed by epiphyses).

Spatial distribution The spatial distribution analysis was carried out in levels F, G, I1, and I2 of the modern collections, whose field spatial data were recorded using appropriate techniques. The open-source software R, through the Spatstat package v. 3.2-1 (https://www.r-project.org/), was used to obtain information on the integrity of the deposit and the alteration processes during the biostratinomic phase and to assess the spatial relationship between faunal remains and lithic tools (Giusti and Arzarello, 2016; Domínguez-Rodrigo et al., 2018; Giusti et al., 2019). To analyze the distribution and relationship between the remains, a window for each archaeological level was constructed to examine the spatial distribution of different items. Corrections for window-edge effects were applied in each case. Nonparametric kernel density maps were generated using bandwidths selected based on sigma values to control the degree of smoothing. Following Berman and Diggle (1989), a mean square error cross-validation method and a likelihood cross-validation method were applied to determine the optimal bandwidth.

Clustering was assessed using the Clark-Evans test through Monte Carlo simulations ($n = 333$) to determine whether the objects were distributed in clusters, indicating a dependency relationship between items; displayed regular dispersion, also suggesting a dependency; or were randomly distributed, implying no spatial relationship. This test was complemented with the Hopkins-Skellam test using Monte Carlo simulations ($n = 300$) as it is less sensitive to inhomogeneity (Baddeley et al., 2015). The distribution of lithic and faunal remains has been analyzed independently through the inhomogeneous L test (Linhom(r) function), being a robust function that measures the cumulative number of points found in a radius of any given point. Fifty random samplings of the data were used in Monte Carlo simulations to obtain the acceptance interval for the functions (Baddeley et al., 2015). A multitype approach was applied to observe spatial co-dependence between both types of remains, using an inhomogeneous cross-type L function (Ripley, 1979).

4. Results

4.1. Ancient collections (1980–1995)

Identification and quantification *Palaeoloxodon antiquus* is the most represented taxon in these assemblages, followed by *Bison schoetensacki*, an unidentified medium-sized cervid, and *Praemegaceros* sp., *Stephanorhinus* sp., or Testudinidae are represented by only one single remain for each. In general, there is a predominance of large ungulates and a total absence of carnivores and smaller taxa (Table 2). Anatomically (SOM Table S1), cranial elements, mainly teeth and dental fragments, are the most representative. *Palaeoloxodon antiquus* is mainly represented by tusk fragments and indeterminate bone fragments. In the case of cervids, antler fragments and some limb bones are also noteworthy, while in the case of *B. schoetensacki*, the recovery of several metapodials is remarkable. It is worth noting the limited presence of smaller specimens, a common problem in ancient excavations that is probably related to methodological shortcomings such as the lack of screening and recovery of smaller remains, as described by Villa (1990).

From this point onward, the data focus on levels D, Sopra E, and I1 as these paleosurfaces hold the highest concentration of remains and provide a solid foundation for taphonomic analysis.

Skeletal representation and preservation Some results were obtained from the estimation of %MAU for the different weight categories (SOM Table S2), although the assemblage is small in terms of bone element quantity across the different weight categories. In level D, shaft's tibia is the single represented element from medium-sized animals. In level Sopra E, the distal tibia and calcaneus show the highest %MAU representation for large-sized carcasses, while among the medium-sized animals, different portions of the limb bones and the talus show the highest values. In level I1, which has a slightly larger assemblage, the scapula has the highest %MAU value for the large size, represented by the glenoid cavity, and the

Table 2
Quantification of the remains that were recovered at the different levels belonging to the ancient collections.

	B	B/C	C	C/D	D	Sopra E	E1	F	Sopra G	I1	I2
Palaeoloxodon antiquus	11/3/1	2/1/1	6/3/2	1/1/1	8/2/1	3/3/1	–	–	–	7/2/1	1/1/1
Stephanorhinus sp.	–	–	–	–	–	–	–	–	–	1/1/1	–
Bison schoetensacki	1/1/1	–	4/3/1	–	5/3/1	10/5/1	–	–	–	10/7/1	–
Bovinae indet.	–	–	–	–	–	–	2/2/1	–	–	–	–
Praemegaceros sp.	1/1/1	–	–	–	–	4/4/1	–	–	–	–	–
Cervidae medium sized	3/3/1	–	5/2/1	–	–	–	–	–	–	13/9/2	5/1/1
Artiodactyla	1/1/–	–	1/–/–	–	–	–	–	–	–	–	–
Testudinidae	–	–	–	–	–	1/1/1	–	–	–	–	–
Total NISP	**17/9/4**	**2/1/1**	**16/8/4**	**1/1/1**	**13/5/2**	**10/13/4**	**2/2/1**	–	–	**31/19/5**	**6/2/2**
Very large	2/–/–	–	4/–/–	–	3/1/–	2/–/–	2/1/1	4/1/1	–	1/–/–	2/–/–
Large	2/–/–	3/2/1	6/–/–	–	7/1/–	13/1/–	2/1/–	2/1/1	–	24/5/–	1/1/1
Medium	6/–/–	2/1/1	14/–/–	–	44/4/1	71/2/–	44/4/1	–	11/1/1	92/10/–	15/3/–
Total weight-size	**10/–/–**	**5/3/2**	**24/–/–**	–	**54/6/1**	**86/3/–**	**48/6/2**	**6/2/2**	**11/1/1**	**117/15/–**	**18/4/1**
Indeterminate	21/–/–	3/–/–	21/–/–	–	46/–/–	75/–/–	34/–/–	3/–/–	10/–/–	59/–/–	13/–/–
Total	**48/9/4**	**10/4/3**	**61/8/4**	**1/1/1**	**113/11/3**	**179/16/4**	**84/8/3**	**9/2/2**	**21/1/1**	**207/34/5**	**37/6/3**

Data are presented as NISP, MNE, or MNI.
MNE = minimum number of elements; MNI = minimum number of individuals; NISP = number of identified specimens.

distal shaft of the humerus for the medium size. Correlation between %MAU and bone mineral density (Fig. 2, top) shows a low positive and statistically significant correlation for medium-sized carcasses from level D (0.0456; $p < 0.003$) and large-sized carcasses from I1 (0.1125; $p < 0.003$). However, the correlation presents an almost null value, reason why the existence of correlation cannot be considered.

Fragmentation and breakage The analysis of the bone breakage patterns and breakage edges of limb bones was carried out on 39 specimens and 103 breakage edges at level D, 62 specimens and 101 breakage edges at level Sopra E, and 64 specimens and 108 breakage edges at level I1. The analysis (Fig. 3) reveals a relatively uniform pattern across the three groups examined, characterized by a high degree of long bone fragmentation and a predominance

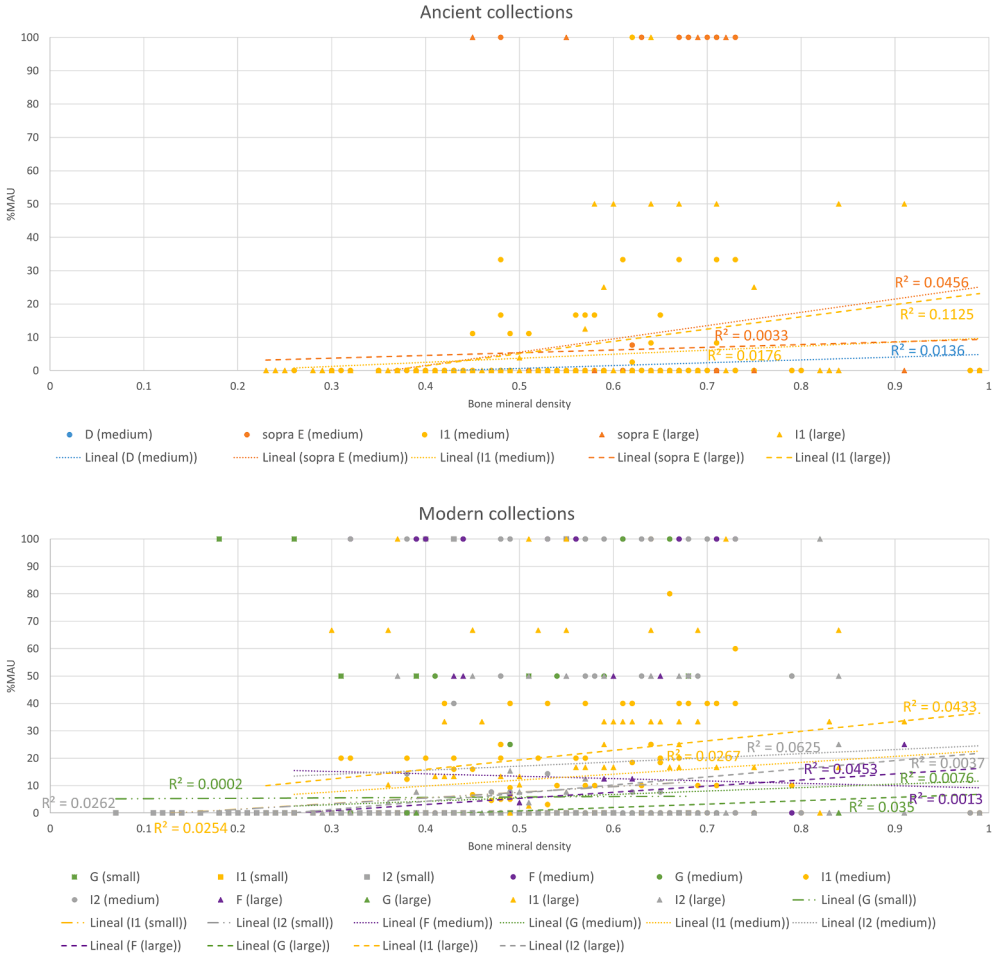

Figure 2. Correlation between %MAU and bone mineral density for the ancient (top) and modern (bottom) collection of Notarchirico. %MAU = minimal animal unit. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

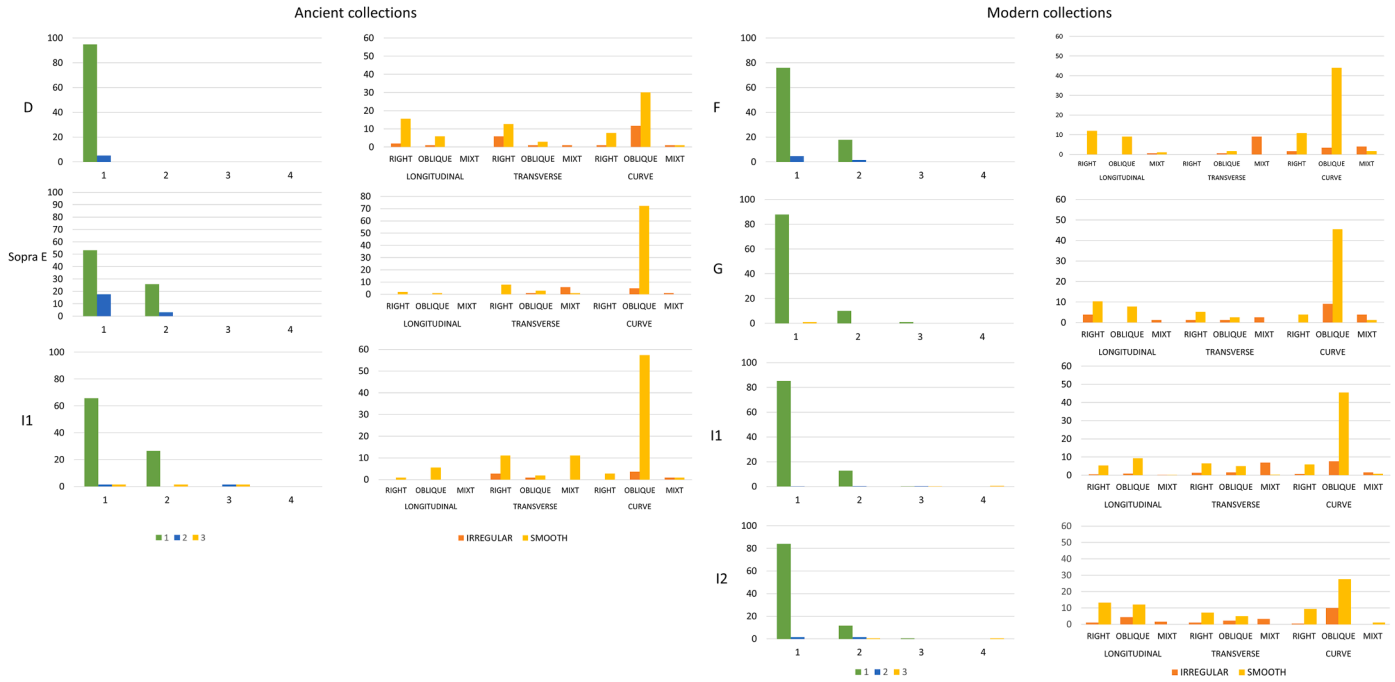

Figure 3. Analysis of the breakage patterns (left column) and breakage edges (right column) of Notarchirico. The left images represent the ancient collection (levels D, Sopra E, and I1), whereas the right images represent the modern collections (levels F, G, I1, and I2). (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

of fractures associated with green bone breakage (curve delineations and oblique angles). However, at level I1, the percentage of remains with right angles, associated with dry breakage, is somewhat more represented.

Green bone breakage evidence has been identified on some remains (Table 3). In level D, conchoidal scars have been observed on four limb bone fragments belonging to a medium-sized animal, while in the level I1, conchoidal scars and pseudonotches have been documented on three medium-sized limb bones. It is not possible to identify the breakage agent in any case.

Bone surface modifications The preservation of bone surfaces across the different assemblages studied at Notarchirico is predominantly poor (between 40% and 60%) or moderate (between 20% and 40%), which has made the conservation and observation of the bone surface modifications difficult (Fig. 4). Well-preserved surfaces that are documented range between 10% and 20% of the cases. No cut marks have been documented. Regarding the rest of the modifications, a similar pattern was documented across the three assemblages, characterized by high pieces of evidence of Fe and Mn coating, a predominance of weathering at low stages (1 and 2, according to Behrensmeyer (1978)) affecting more than 50% of the sample from each level, and low evidence of water-induced modifications (~10%) (Fig. 5). The main difference is documented concerning root etching, with values close to 20% in levels D and Sopra E, whereas it is documented in more than half of the sample in I1.

Ratios of preservation of bones and bone portions High disappearance of epiphyses has been estimated across all assemblages through the estimated epiphysis-to-shaft ratio. Proximal humerus and distal radius portions show low values in level I1, indicative of the total absence of those elements. Axial-to-limb ratios show moderate to high disappearance of those elements (Table 5).

The correlation between the axial-to-limb ratio and the HP + RD-to-HD + RP ratio suggests high levels of ravaging (stage 3) for level I1 (Fig. 6, top), according to the model proposed by Domínguez-Rodrigo and Organista (2007), whereas all levels fall outside the Egeland's theoretical model (2008) (Fig. 6, bottom). The percentage of change (Table 6) shows a total disappearance of the epiphysis in level D, in which only one tibia was documented, and moderate-to-high disappearance in the levels Sopra E and I1, in which there is a more diverse representation of the different limb bones.

4.2. Modern collections (2016–2024)

Identification and quantification Modern collections show high taxonomic and anatomic variability, including ungulates of all weight-size categories, with *Pal. antiquus*, *Ce. elaphus*, *B. schoetensacki*, and *Praemegaceros* sp. being the most represented taxa throughout the lowest levels of the sequence. The documentation of *Dama*-like deer, indicative of the presence of at least three different cervids in the area at least during the formation of levels G and I1, is also noteworthy. Carnivores are presented by *Ca. mosbachensis* in levels G and I, as well as *Martes* sp. in levels H and I1. *Castor fiber*, leporids, and birds complete the taxonomical list (Table 7). Anatomically (SOM Table S3), there is a greater diversity, especially among the predominant taxa, although dental elements remain the most represented. Notably, level I1 stands out as the richest in fossils in the entire assemblage, where a large portion of the skeletal elements of *Ce. elaphus* and *B. schoetensacki* have been identified.

From this point onward, the data focus on levels DF, G, I1, and I2 as these levels hold the highest concentration of remains and provide a solid foundation for taphonomic analysis.

Skeletal representation and preservation The estimation of %MAU for the different weight categories (SOM Table S4) shows high values for the tibia's shaft in the large-size group and the mandibular body and some portions of limb bones in the medium-size category. In level F, the highest values are again found in the tibia's shaft (large size), mandible and limb bone portions

Table 3
Modifications associated to the fragmentation and breakage identified at Notarchirico.

	Ancient collections						Modern collections							
	D		Sopra E		I1		F		G		I1		I2	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Conchoidal scars	4	3.5	2	1.1	–	–	2	0.6	1	0.2	6	0.4	1	0.2
Cortical extractions	–	–	–	–	–	–	–	–	1	0.2	–	–	–	–
Pseudonotches	–	–	1	0.6	–	–	–	–	1	0.2	2	0.1	–	–
Split phalanx	–	–	–	–	–	–	–	–	–	–	1	0.05	–	–

Table 4
Bone surface modifications identified at Notarchirico.

		Ancient collections						Modern collections							
		D		Sopra E		I1		F		G		I1		I2	
		n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Total NSP		113	100	179	100	207	100	15	100	417	100	1587	100	541	100
Tooth marks		–	–	–	–	3	1.4	–	–	2	0.5	20	1.3	2	0.6
Weathering	W0	36	31.9	79	44.1	62	30	196	62.2	256	61.4	1187	74.8	252	46.6
	W1	53	46.9	57	31.8	88	42.5	91	28.9	117	28.1	353	22.2	238	44
	W2	13	11.5	29	16.2	42	20.3	20	6.3	40	9.6	45	2.8	47	8.7
	W3	8	7.1	12	6.7	15	7.2	8	2.5	4	1	2	0.1	4	0.7
	W4	3	2.7	2	1.1	–	–	–	–	–	–	–	–	–	–
Rounding	R0	99	87.6	151	84.4	188	90.8	241	76.5	306	73.4	1311	82.6	481	88.9
	R1	9	8	16	8.9	11	5.3	46	14.6	26	6.2	121	7.6	26	4.8
	R2	5	4.4	12	6.7	8	3.9	26	8.3	71	17	149	9.4	34	6.3
	R3	–	–	–	–	–	–	2	0.6	14	3.4	6	0.4	–	–
Polishing	P0	102	90.3	153	85.5	189	91.3	253	80.3	309	74.1	1361	85.8	487	90
	P1	1	0.9	21	11.7	17	8.2	49	15.6	52	12.5	161	10.1	49	9.1
	P2	10	8.8	5	2.8	1	0.5	13	4.1	56	13.4	65	4.1	5	0.9
Trampling		3	2.7	6	3.4	4	1.9	23	7.3	8	1.9	60	3.8	8	1.5
Root-etching		18	15.9	41	22.9	114	55.1	92	29.2	281	67.4	476	30	243	44.9
Gnawing		–	–	–	–	–	–	–	–	–	–	2	0.1	–	–
Mn coating		108	95.6	147	82.1	183	88.4	232	73.7	304	72.9	872	54.9	426	78.7
Fe coating		88	77.9	117	65.4	176	85	188	59.7	281	67.4	937	59	443	81.9
Fissures		12	10.6	25	14	21	10.1	66	21	58	13.9	235	14.8	17	3.1
Dissolution		3	2.7	8	4.5	7	3.4	2	0.6	9	2.2	41	2.6	13	2.4
Cementations		–	–	1	0.6	10	4.8	–	–	10	2.4	177	11.2	135	25
Deformations		–	–	1	0.6	–	–	1	0.3	–	–	1	0.05	–	–

NSP = number of specimens.

(medium size), and the ulna (small size). In level I1, the most represented elements are the calcaneus (large size), the acetabulum of the coxal bone (medium size), and the proximal phalanx (small size), while in level I2, they include the acetabulum, talus, and some limb bone portions (large size), the tibia' shaft (medium size), and the proximal and distal phalanges (small size).

The correlation between %MAU and bone mineral density (Fig. 2, top) shows a low positive correlation in all cases (Fig. 2, bottom), but just large-sized animals from level F (0.0453; $p < 0.05$) and I1 (0.0433; $p < 0.003$) have statistically significant correlation with low values (near to 0), suggesting no relationship between the preserved sample and its density.

Fragmentation and breakage The analysis of the bone breakage patterns and breakage edges of long bones was carried out on 129 specimens and 175 breakage edges at level F, 90 specimens and 77 breakage edges at level G, 492 specimens and 769 breakage edges in level I1, and 206 specimens and 181 breakage edges at level I2. Overall, the four assemblages exhibit high levels of breakage and a predominance of green breakage; however, the I1 and I2 assemblages, like level I1 in the older collections, show a greater presence of dry breakage (Fig. 3).

Regarding other breakage evidence, conchoidal scars, a cortical extraction, and pseudonotches have been documented on medium- and large-sized limb bones, one of which has been identified as a medium-sized humerus (Table 3). In none of these cases was it possible to identify the breakage agent. The only exception is a second phalanx of a deer from level I1, which has been categorized as split phalanx, hence being indicative of anthropogenic breakage (Jin and Mills, 2011).

Bone surface modifications The preservation of bone surfaces follows a common pattern with the ancient collections in most assemblages (Fig. 4), with a predominance of poorly or moderately preserved surfaces and approximately 20% of bones classified as well preserved. The only exception is level I2, where surfaces are more altered, and the percentage of well-preserved surfaces is lower than 10%. Anthropic and carnivore activity remains low; incisions were identified on a rib belonging to a medium-sized animal in level I1 and on a flat bone belonging to a large-sized carcass in level I2. Carnivore activity is also poorly documented, with values around 1% in levels G, I1, and I2. Regarding the rest of the modifications (Table 4), the observed pattern differs significantly from the ancient collections (Fig. 5). Weathering is documented in near 50% of the cases, except in level I2, and mostly appears in stage 1. Similarly, rounding and polishing affect around 20–25% of the sample, except in level I2, where it is slightly above 11%. Fe and Mn coating are also noteworthy.

Ratios of preservation of bones and bone portions The estimated epiphysis-to-shaft ratio suggests a high disappearance of

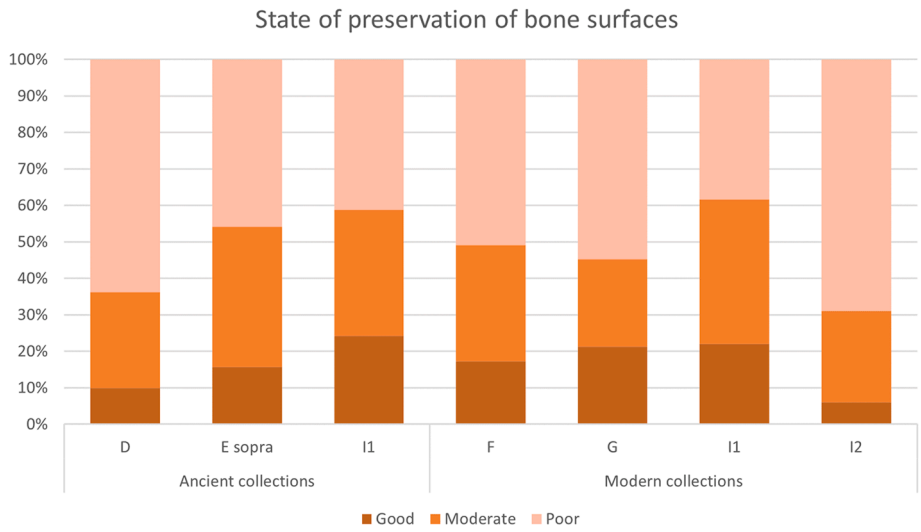

Figure 4. State of preservation of the bone surfaces at Notarchirico. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

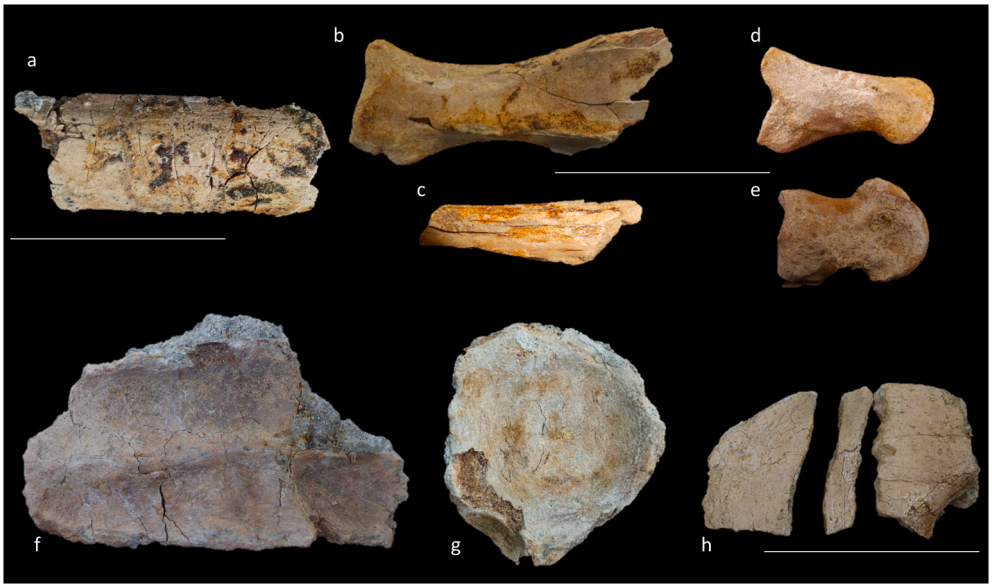

Figure 5. Bone remains recovered from both ancient and modern collections. The state of preservation of the surfaces can be seen. A) A rib fragment belonging to a very-large-sized mammal (NOT2017-G-A24-40); B) the scapula of *Bison schoetensacki* (NOT2022-I1-A36-37); C) a shaft fragment belonging to a medium-sized mammal (NOT-E-43); D) the first phalanx of *B. schoetensacki* (NOT2024-I1-D35-47); E) the second phalanx of *B. schoetensacki* (NOT2024-I1-D35-17); F) a flat bone fragment belonging to *Palaeoloxodon antiquus* (NOT2024-G-C23-56); G) the vertebra of *P. antiquus* (NOT2018-G-B25-3); H) a flat bone fragment belonging to *P. antiquus* (NOT2024-G-C23-55). Scale bars: 8 cm (a–e), 15 cm (f–h). Images are allowed by the agreement of the Italian Ministry of Culture and the Museo Parco Archeologico Melfi e Venosa. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

epiphyses across all assemblages. Moderate results were obtained for the preservation of proximal humerus portions and distal radius, as well as axial elements in all assemblages where estimations were possible (Table 5).

The correlation between the axial-to-limb ratio and the HP + RD-to-HD + RP ratio suggests moderate levels of ravaging (stage 2) for level I2 and high levels (stage 3) for levels F and I1 (Fig. 6, top), according to the model proposed by Domínguez-Rodrigo and Organista (2007). The correlation between the axial-to-limb ratio and the epiphysis-to-shaft ratio suggests high competition scenarios for all assemblages (Fig. 6, bottom), based on Egeland's theoretical model (2008).

The estimated percentage change across different levels (Table 6) shows a relatively high disappearance of epiphyses in levels F and G, which sometimes becomes complete. In levels I1 and I2, epiphyseal disappearance is somewhat more moderate. Only in the case of the radius-ulna from level I1 do we observe relatively high preservation of epiphyses as the estimated values indicate a 25% disappearance.

The correlation between the %MAU of the long bones ends and their mineral density (Table 8) suggests positive and negative correlations but close to 0 and without statistical significance. According to the premises given by Faith and Behrensmeyer (2006) and Faith et al. (2007), a low and not-statistically significant

Table 5
Estimation of the skeletal and portions ratios at the different levels of Notarchirico.

Ratios	Ancient collections			Modern collections			
	D	Sopra E	I1	F	G	I1	I2
Epiphysis-to-shaft	0	0.03	0.11	0.04	0.03	0.05	0.05
HP + RD-to-HD + RP	–	–	0	0	–	0.11	0.5
Axial-to-limb	1	1	1.2	0	0.4	0.52	0.5

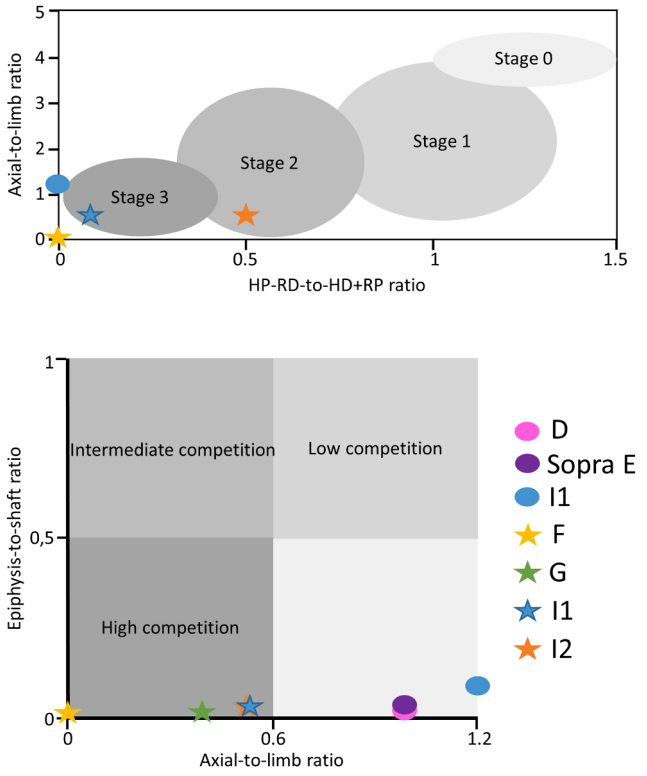

Figure 6. Distribution of the Notarchirico assemblages in A) the model proposed to evaluate stages of ravaging in archaeological assemblages, adapted from Domínguez-Rodrigo and Organista (2007); and B) the theoretical model proposed to estimate levels of competition between predators in the assemblages, adapted from Egeland (2008). Circles represent the ancient collections, whereas stars represent the modern ones. Data are taken from Table 5. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

Table 6
Estimation of the percentage of change at the different levels of Notarchirico to evaluate the disappearance of epiphyses.

	Ancient collections			Modern collections				
	D	Sopra E	I1	F	G	I1	I2	Total
Humeri	–	50	75	100	100	75	75	**87.5**
Radii-ulnae	–	100	100	75	–	60	25	**53.3**
Femora	–	–	–	50	100	50	–	**66.7**
Tibiae	100	50	100	75	100	75	75	**81.3**
Metapodials	–	–	50	50	50	50	60	**52.5**
Total	**100**	**66.7**	**65**	**75**	**75**	**62.5**	**59.1**	**67.9**

correlation could be indicative of high competition as all elements are destroyed regardless of their mineral density. However, the samples are relatively small and the lack of significant correlations could also be a consequence of a type II error (Faith and Gordon, 2007), where two correlated variables show an absence of statistical significance due to small sample sizes. Therefore, these data should be considered more indicative than conclusive.

Water flow transport Through the classification of the assemblages according to the categories established by Voorhies (1969) (Table 9), we can infer that level F, where remains attributed to group II predominate, could correspond to an assemblage affected by moderate displacement and velocity. Levels G and I1 show a similar pattern, with a predominance of remains attributed to group I and, to a lesser extent, to Group II, a characteristic of lagged assemblages. Finally, in level I2, remains from groups I and II predominate, which Voorhies (1969) describes as the result of high velocity and significant displacement. It is important to consider that this analogy only takes into account complete bones and small sizes, so any inference should be interpreted with caution.

Dense bones dominated the assemblages F and G, whereas dense and mixed bones are predominant in the levels I1 and I2 (Table 10; Fig. 7). In relation to shape, cube bones are predominant in the whole assemblage, which is related to nonperturbed assemblages. According to the structure of the bones which seems to be the most explicate variable (Domínguez-Rodrigo et al., 2018), the assemblages of levels F and G could fit with lagged assemblages. The combination of that data is indicative of a mixture of materials that would have been affected by various processes.

Spatial distribution A total of 575 remains from level F were included in the spatial distribution analysis, 235 of which are faunal remains and the remaining 340 are stone tools. Smoothing Kernel density maps revealed a clear overlap between all materials in the eastern excavated area (Fig. 8), although the lithic remains show a greater dispersion than the faunal remains (Fig. 9). This interpretation is supported by the Clark-Evans test, which suggests a higher clustering of lithic remains (R = 0.74025; $p \leq$ 2.2e−16) than in faunal remains (R = 0.66969; $p \leq$ 2.2e−16), as well as the Hopkins-Skellam test of complete spatial randomness (CSR), which also suggests aggrupation patterns for both materials but higher for lithic remains (A = 0.071387; $p \leq$ 2.2e−16) than for faunal remains (A = 0.18518; $p \leq$ 2.2e−16). The inhomogeneous L test (Linhom(r) function) (Fig. 10), on the contrary, suggests a dispersion pattern for faunal remains, while describing a random pattern in the case of stone tools. The multitype test (Lcross.inhom(r) function) (Fig. 11) suggests a random pattern at short distances, with a tendency toward regular dispersion at longer distances. These patterns are consistent with fluvial processes.

The spatial distribution analysis of level G includes a total of 796 items, comprising fauna (n = 318) and lithics (n = 478). Smoothing Kernel density maps also revealed an overlap of materials at that northern area excavated in that level (Fig. 7), with lithic remains showing greater dispersion than faunal remains (Fig. 8). The Clark-Evans test provides similar values for lithic remains (R = 0.75446; $p <$ 2.2e−16) and faunal remains (R = 0.73935; $p <$ 2.2e−16), suggesting a higher clustering of both groups. The Hopkins-Skellam test of CSR also indicates aggregation patterns for both materials, with more pronounced values for lithic remains (A = 0.089488; $p <$ 2.2e−16) than for faunal remains (A = 0.14164; $p <$ 2.2e−16). According to both the inhomogeneous L test (Linhom(r) function) (Fig. 9) and the multitype test (Lcross.inhom(r) function) (Fig. 10), lithic and faunal remains show a trend toward intraspecific spatial aggregation patterns as the distances between items increase.

The number of remains included in level I1 totals 1659, of which 1223 are faunal remains and the remaining 436 are stone tools. Kernel maps not only revealed a main area of aggregation of remains in the northeastern area (trench) (Fig. 7) but also showed a second area with a small aggregation of faunal remains in the southern excavated area (Fig. 8). The Clark-Evans test suggests a clustering pattern for both lithic (R = 0.79144; $p <$ 2.2e−16) and faunal remains (R = 0.76311; $p <$ 2.2e−16). In a similar way, the Hopkins-Skellam test of CSR also indicates aggregation for both

Table 7
Quantification of the remains that were recovered at the different levels belonging to the modern collections.

	E/F	F	G	H	I1	I2
Macaca sp.	–	–	2/2/1	–	–	–
Palaeoloxodon antiquus	2/1/1	23/3/1	34/4/1	1/1/1	14/4/2	15/5/1
Stephanorhinus sp.	–	–	2/2/1	–	2/2/1	4/1/1
Hippopotamus sp.	–	–	2/1/1	–	3/2/1	2/2/1
Bison schoetensacki	6/1/1	19/11/2	2/1/1	–	44/30/5	15/8/2
Praemegaceros sp.	–	–	1/1/1	2/2/1	15/14/4	6/4/1
Cervus elaphus	2/2/1	8/4/1	20/7/1	11/7/1	173/59/6	34/8/1
Dama-like deer	–	–	1/1/1	–	1/1/1	–
Artiodactyla	–	–	4/–/–	–	5/–/–	2/–/–
Perissodactyla	–	–	1/–/–	–	–	–
Canis mosbachensis	–	–	2/1/1	–	1/1/1	3/2/1
Martes sp.	–	–	–	1/1/1	1/1/1	–
Mustelidae	–	–	–	–	7/7/–	–
Castor fiber	–	–	–	–	1/1/1	–
Leporidae	–	–	–	1/1/1	3/3/1	1/1/1
Aves	–	–	1/1/1	–	2/2/1	–
Testudinidae	–	–	8/1/1	–	1/1/1	1/1/1
Total NISP	**10/4/3**	**50/18/4**	**80/22/11**	**16/12/5**	**273/128/26**	**83/32/10**
Very large	1/–/–	5/–/–	33/–/–	1/1/–	11/–/–	13/2/–
Large	42/1/–	48/4/1	32/3/–	4/2/–	237/14/–	52/3/–
Medium	47/4/–	114/3/–	90/4/–	42/3/–	747/12/–	255/6/–
Small	–	–	3/–/–	2/2/1	13/18/–	7/2/1
Very small	–	–	–	–	2/1/–	1/1/–
Total weight-size	**90/5/–**	**167/7/1**	**158/7/–**	**49/8/1**	**1010/45/–**	**328/14/1**
Indeterminate	34/–/–	98/–/–	179/–/–	18/–/–	304/–/–	130/–/–
Total	**134/9/3**	**315/25/5**	**417/29/11**	**83/20/6**	**1587/173/26**	**541/46/11**

Data are presented as NISP, MNE, or MNI.
MNE = minimum number of elements; MNI = minimum number of individuals; NISP = number of identified specimens.

lithic (A = 0.1876; $p < 2.2e{-}16$) and faunal remains (A = 0.12347; $p < 2.2e{-}16$). The inhomogeneous L test (Linhom(r) function) (Fig. 9) suggests a tendency toward intraspecific spatial aggregation patterns as the distances between items increase, as also indicated by the multitype test (Lcross.inhom(r) function) (Fig. 10).

Finally, a total of 654 remains from level F were included in the spatial distribution analysis, 492 of which are faunal remains and the remaining 133 are stone tools. Smoothing Kernel density maps revealed a clear overlap between all materials in the southern area (Fig. 7), although when shown fauna and lithics separately is documented a second, more modest, aggregation of lithic remains in the southwestern area (Fig. 8). The Clark-Evans test provides similar values for lithic remains (R = 0.70729; $p < 2.2e{-}16$) and faunal remains (R = 0.6665; $p < 2.2e{-}16$), suggesting a higher clustering of both groups. On the other hand, the Hopkins-Skellam test of CSR also suggests aggregation patterns for both materials but with higher clustering for faunal remains (A = 0.072222; $p < 2.2e{-}16$) than for lithics (A = 0.18251; $p < 2.2e{-}16$). The inhomogeneous L test (Linhom(r) function) (Fig. 9) indicates a trend of intraspecific spatial aggregation patterns increasing as the distances between items grow, as is also indicated by the multitype test (Lcross.inhom(r) function) (Fig. 10).

5. Discussion

Notarchirico is an open-air archaeopaleontological site formed in a fluviodeltaic sedimentary environment. Its sequence spans a chronological range of nearly 100 ka during the early Middle Pleistocene (695–610 ka), making it one of the key sites for studying hominin behavior during the Middle Pleistocene. The recent paleontological review by Mecozzi et al. (2024b) has identified three faunal complexes throughout the Notarchirico sequence: the lower complex characterized by the predominance of wooded spaces, sparse steppes, and the presence of water bodies (lakes or ponds), corresponding to levels I2–G and associated with the deterioration of fully interglacial conditions recorded at the end of MIS 17; the middle complex, corresponding to levels G–C, characterized by a low number of mammal remains, attributed to the glacial conditions of MIS 16; and the upper complex, characterized by an improvement in the climate, corresponding to levels B–Sopra α, marking a transition toward the fully interglacial conditions that would emerge during MIS 15.

Based on the variety of species identified throughout the entire sequence of Notarchirico (Mecozzi et al., 2021a, 2024b; Iannucci et al., 2024; present paper), the inferred ecological mosaic was likely complex. The reconstructed landscape was primarily characterized by open and semiopen areas inhabited by the most represented species such as bison, elephants, and a wide variety of cervids (Mecozzi et al., 2024b). However, the presence of large bodies of water in the area is also suggested by the recovery of taxa associated with aquatic environments, such as hippopotamuses and beavers. Additionally, riparian environments were represented by taxa like macaques (Mecozzi et al., 2021b) and wild boars. Carnivores and hominins represent the predators' niche. The carnivore material is scarce and just limited to a single lion metapodial recovered from level A (Iannucci et al., 2024) and some remains of wolves and martens identified in the lowest levels of the sequence. At this point, it is important to consider the absence of screening methods during the excavation of the upper levels of the sequence, which could explain, at least in part, the absence of the smallest taxa which are almost totally absent in the archaeological record. Hominin groups were identified throughout the sequence through the abundant stone tools recovered (Moncel et al., 2019, 2020, 2023; Santagata et al., 2020; Carpentieri et al., 2023) and by a femoral fragment belonging to a young adult individual recovered from level α and recently reattributed to *H. heidelbergensis* (Micarelli et al., 2024). This human remain is the oldest one in the Italian Peninsula and one of the oldest human fossils associated with Acheulean tools in the European archaeological record. Despite the presence of faunal remains in the same deposit as the human remain, no taphonomic evidence of

Table 8
Correlation of the %MAU of the limb bones ends, according to Faith and Behrensmeyer (2006) and Faith et al. (2007).

		Kenddall's tau	*p* value
F	Medium	−0.277	>0.005
G	Small	0.15	>0.005
	Medium	0.15	>0.005
I1	Medium	0.099	>0.005
	Large	−0.053	>0.005
I2	Medium	−0.166	>0.005
	Large	0.083	>0.005

Table 9
Classification of the osteological sample of levels F, G, I1, and I2 according to the Voorhies (1969) groups.

	Group I	Group I - II	Group II	Group II-III	Group III
F	10.8	13.5	64.9	0.0	10.8
G	52.4	11.9	26.2	0.0	9.5
I1	58.3	10.3	21.1	0.5	9.8
I2	45.8	4.8	44.6	0.0	4.8

Data are presented in percentage.

anthropic processing was documented. The only evidence of activity is stone tools, which do not appear to be related to the faunal carcasses. This aligns with the rest of the sequence, data of which are presented in this study.

A spatial analysis has been conducted in this work and allows for the identification of distinct patterns of formation in the studied assemblages. When integrated with previous spatial (Moncel et al., 2023) and sedimentological (Mecozzi et al., 2024b) studies, these patterns facilitate the advancement of the interpretation of the formation processes of the bottom of the sequence. In level G, there is a clear spatial overlap of lithic and faunal remains in the north of the excavated area, with a greater dispersion of lithic remains. The aggregation model inferred suggests that level G could be a lagged assemblage in which some materials have been lost due to low-energy water currents, preferentially affecting the lighter and less dense elements; in terms of faunal remains, this results in an under-representation of small elements and spongy specimens. This finding is consistent with the evidence of abrasion and patinas described in Moncel et al. (2023) for lithics, which supports the idea that the assemblage was affected by hydrodynamic processes. Such processes have been shown to generate lagged assemblages (Domínguez-Rodrigo et al., 2018). The formation of level F shows, despite the spatial overlap in the southern part of the excavated area, a clear tendency toward regular dispersion, especially for lithic remains. A secondary aggregation is observed in the southwestern area, without an evident pattern of co-occurrence with faunal remains. As shown in previous spatial studies (Moncel et al., 2023), the data reflect a distribution lacking preferential orientation or significant concentration, likely associated with low-intensity processes.

The formation of level I1 corresponds to a distinct pattern. The higher density of remains and the clear concentration in the northeast area, accompanied by a secondary aggregation pattern of fauna in the south, suggest less impact from water currents. This is based on the identification, in the case of fauna, of a higher frequency of mixed bones but few trabecular ones, suggesting that the influence of water currents is likely even lower than in levels G and F, resulting in the preservation of pre-existing aggregations. The substantial aggregation of lithics and faunal remains, a phenomenon that is particularly evident in the first group, also suggests that water currents might not have played a significant role in the dispersion of these items. The intraspecific trends observed in the aggregation patterns could be related to limited post-depositional rearrangements. The observed spatial separation between the two accumulation zones may be attributed to the occurrence of distinct accumulation events. Level I2 displays a comparable pattern, with a propensity toward increased aggregation for fauna and wider dispersion for lithic remains (SOM Fig. S2).

The taphonomic data presented herein may facilitate a more profound comprehension of the formation processes of Notarchirico. The bone structure pattern suggests that most of the levels may be lagged, a fact that is congruent with the inferred environment of the site, which may be subject to seasonal flooding and water flows. Water currents may have played a role in the conservation, reduction, or dispersal and modification of the excavated assemblages, suggesting that should be considered as an additional taphonomic agent influencing the site formation processes. In view of these patterns, it is now pertinent to examine the role of hominin groups in shaping the archaeological record.

From a sedimentological and taxonomical point of view, the scenario depicted in Notarchirico is that of a landscape with flowing water, seasonally flooded areas, and relative taxonomic diversity, suggesting a high availability of resources. Those landscapes represent an environment for hominin transit since the late Early Pleistocene, in search of various resources such as fresh water, vegetables, and raw materials for toolmaking, as well as meat from animal carcasses in coexistence with other predators (Binford, 1981, 1983; Díez, 1993; Egeland et al., 2004; Barba and Domínguez-Rodrigo, 2007; Domínguez-Rodrigo and Barba, 2007; Domínguez-Rodrigo et al., 2007, 2010; Egeland, 2008, 2014; Pineda et al., 2017, 2020). Unfortunately, these open-air environments often make it challenging to identify the exploitation of animal resources not only due in many cases to issues such as poor preservation of bone surfaces and anthropogenic modifications (Shipman and Rose, 1983; Díez Fernández-Lomana et al., 1997; Villa et al., 2005; Egeland, 2007, 2008; Egeland and Domínguez-Rodrigo, 2008; Pineda et al., 2017, 2020; Pineda and Saladié, 2022) but also because they are high-intensity activity areas

Table 10
Classification of the osteological sample of levels F, G, I1, and I2 according to the bone structure and shape according to Domínguez-Rodrigo and colleagues (2018).

		F	G	I1	I2
Bone structure	Cancellous	4.6	12.2	3.1	2.3
	dense	75.9	62.8	46.5	48.1
	Mixed	19.5	25	50.4	49.6
		F	G	I1	I2
Shape bone	Cube	73.1	82.8	73.3	74.3
	Flat	26.5	17.2	26.5	24.5
	Tube	0.4	0	0.2	1.2

Data are presented in percentage.

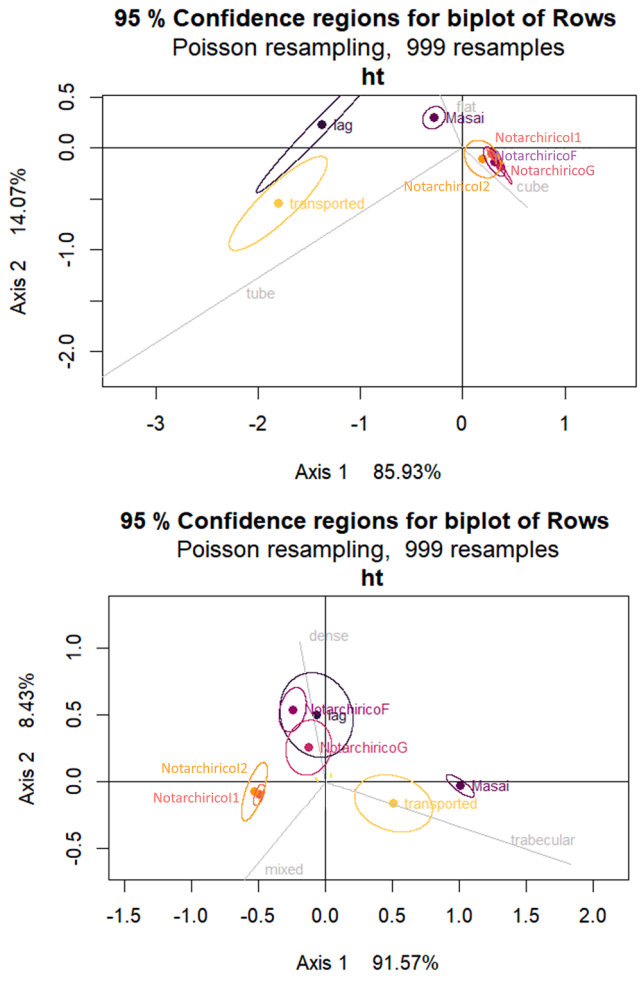

Figure 7. Correspondence analysis displaying the relationships of a lagged, dragged, and home base Masai assemblage and Notarchirico according the shape (top) and the structure (bottom) of the bones. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

involving various types of movements, whose signals in the archaeological record may be subtle. Despite the absence of cut marks or other direct evidence of anthropic processing (Piperno, 1999; present paper), the '*elephant butchery area*' of Notarchirico was initially published as a butchering site by the supposed spatial association between the elephant remains and the stone tools (Cassoli et al., 1993; Piperno, 1999; Piperno and Tagliacozzo, 2001), but the reanalysis and reinterpretation of the faunal and lithic materials recovered in this area has found no reliable proofs to consider these remains as result of a butchery event (Pineda et al., 2024).

Indeed, the association of megafauna skeletal remains (elephants, mammoths, rhinoceroses, or hippopotamuses) and lithic industry in fluvial-lacustrine depositional contexts is a relatively common occurrence in the European Lower and Middle Pleistocene (Konidaris and Tourloukis, 2021), particularly in the southern peninsulas. The following cases have been described: Torralba and Ambrona (Aguilera y Gamboa, 1913; Villa, 1990; Villa et al., 2005; Pineda and Saladié, 2019), Fuente Nueva 3 (Espigares et al., 2013; Yravedra et al., 2024), Pit 1 of Barranc de la Boella (Mosquera et al., 2015; Fidalgo et al., 2025), and several sites in the valleys of the Manzanares and Jarama rivers (Yravedra et al., 2010, 2012, 2014) in the Iberian Peninsula, as well as Fontana Ranuccio and Castel di Guido (Boschian and Saccà, 2015; Boschian et al., 2019) or the site of Cimitero di Atella (Rocca et al., 2021, 2023), a nearby site located few kilometers from Notarchirico, in Italy, and Marathousa 2 (Konidaris et al., 2023) in Greece. Most of these sites were originally interpreted as '*butchering sites*.' However, it is now widely accepted that the simple spatial association of megafauna bones with lithic tools does not necessarily imply a past interaction between the fauna and the hominin groups (Domínguez-Rodrigo, 2008; Palombo and Cerilli, 2021).

Evidence is required to demonstrate this interaction, such as cut marks on bones. Cut marks have been described in some assemblages such as Barranc de la Boella (Mosquera et al., 2015; Fidalgo et al., 2025) or Ardios 2 (Yravedra et al., 2010). However, the identification of such sites during these periods is challenging (Palombo and Cerilli, 2021), and thus, indirect evidence, such as lithic refits, in addition to evidence of carcass processing (e.g.,

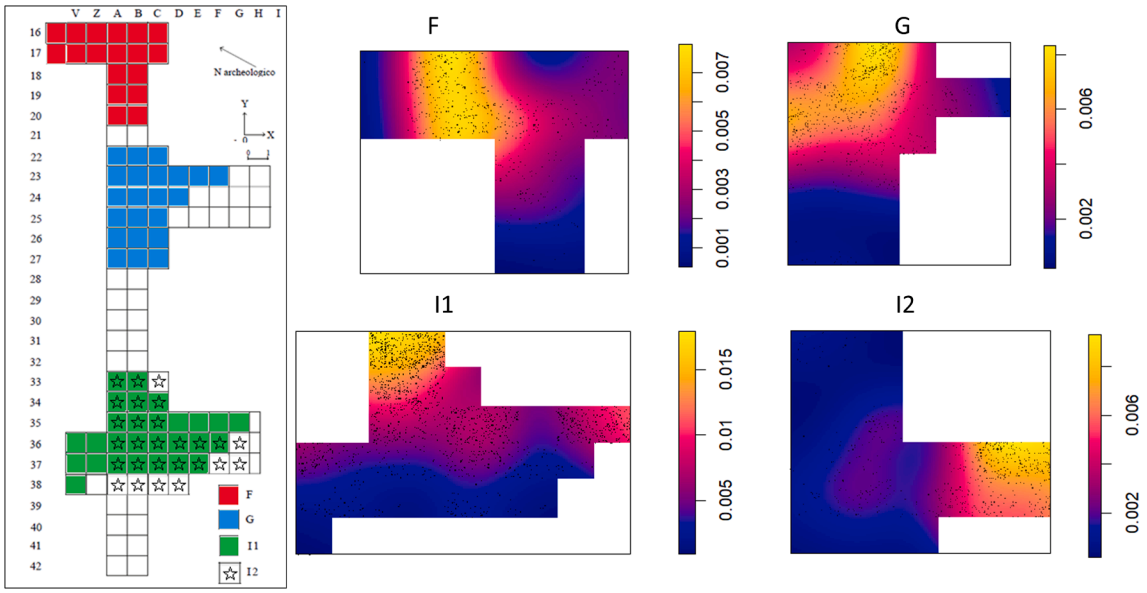

Figure 8. Left) View of the excavated new area at Notarchirico (2016–2024) and different areas excavated in each level. Right) Smoothing Kernel density map of remains from levels F, G, I1, and I2. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

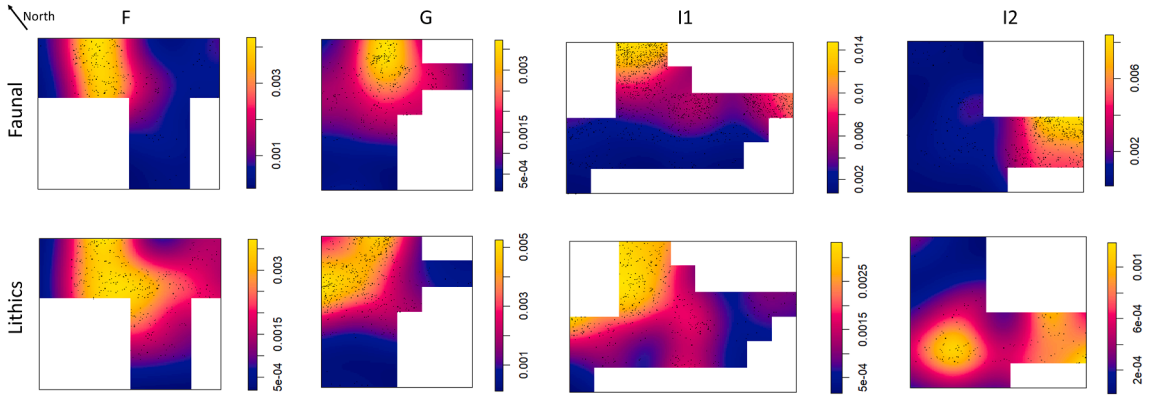

Figure 9. Smoothing Kernel density map of faunal (top) and lithic (bottom) remains from Notarchirico levels F, G, I1, and I2. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

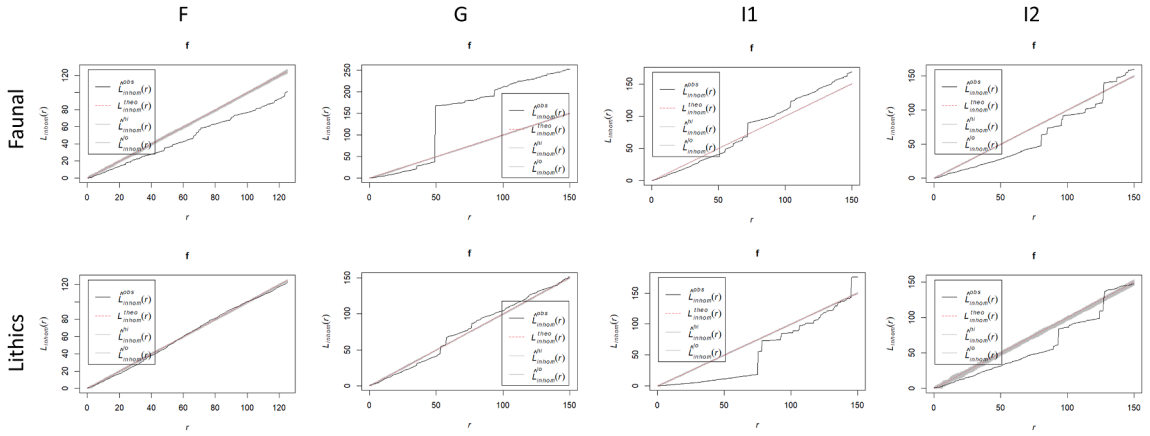

Figure 10. Inhomogeneous L test of faunal (top) and lithic (bottom) remains from Notarchirico levels F, G, I1, and I2. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

skinning or meat removal) on the stone tool edges associated with faunal remains, is considered strong evidence supporting the identification of a butchering site (Palombo and Cerilli, 2021). The review of these associations in recent decades has been put on hold pending further review (Domínguez-Rodrigo, 2008) in some cases such as Cimitero di Atella (Rocca et al., 2021, 2023) or has directly led to their rejection, as in the case of Torralba (Villa et al., 2005; Pineda and Saladié, 2022) or Notarchirico itself (Pineda et al., 2024).

There is no doubt that human groups were knapping tools at Notarchirico or in its surrounding area (Moncel et al., 2020, 2023) and that they were used to exploit the resources provided by the landscape. However, the origins of the faunal remains are more uncertain as most of them may not be directly related to anthropic exploitation and likely have diverse origins. A recent taphonomic review of the neighboring site of Loreto, in which the cortical bone surfaces are better preserved, has shown signals of medium- and large-sized carcass processing that would include most butchery activities (skinning, disarticulation, defleshing, and accessing bone marrow) (Pineda et al., 2025). Although the evidence from Loreto cannot be directly used to infer similar behaviors at Notarchirico, it can be useful for exploring the adaptive capabilities of Middle Pleistocene hominins in this region. First, these data attest to the existence of exploitable faunal resources in the basin, as also documented at Notarchirico. However, the inadequate preservation of bone surfaces at Notarchirico prevents a clear identification of the anthropogenic role in carcass processing at the site. This may be due to the previously mentioned preservation issues, which commonly affect surfaces and bone surface modifications in ancient Pleistocene open-air sites (e.g., Domínguez-Rodrigo et al., 2007, 2010; Egeland, 2008; Pineda et al., 2017, 2020; Pineda and Saladié, 2022). The only exception is the split phalanx belonging to a deer and recovered from level I1, which shows signals of anthropogenic breakage (Jin and Mills, 2011) and attests to this discrete access to faunal resources. Had carcass processing been more intensive and originally left evidence in the form of cut marks, these could have been obliterated over time. However, it is also possible that carcasses were never processed in significant quantities at the site and that the spatial relationship between faunal and lithic remains be casual and not because there is a temporary relationship between those elements, in a similar way to those described in the '*elephant butchery area*' (Pineda et al., 2024).

While the almost total absence of anthropogenic signals on bone surfaces prevents us from establishing direct relationships between hominins and fauna in terms of carcass acquisition and processing (Domínguez-Rodrigo et al., 2010a, 2010b; Pineda and Saladié, 2022), we can still make behavioral and paleoecological inferences on a broader scale, particularly with regard to competition and interaction with other predators in the region. The complete absence of cut marks at Notarchirico contrasts with the lithic assemblage, which is well preserved and abundant and

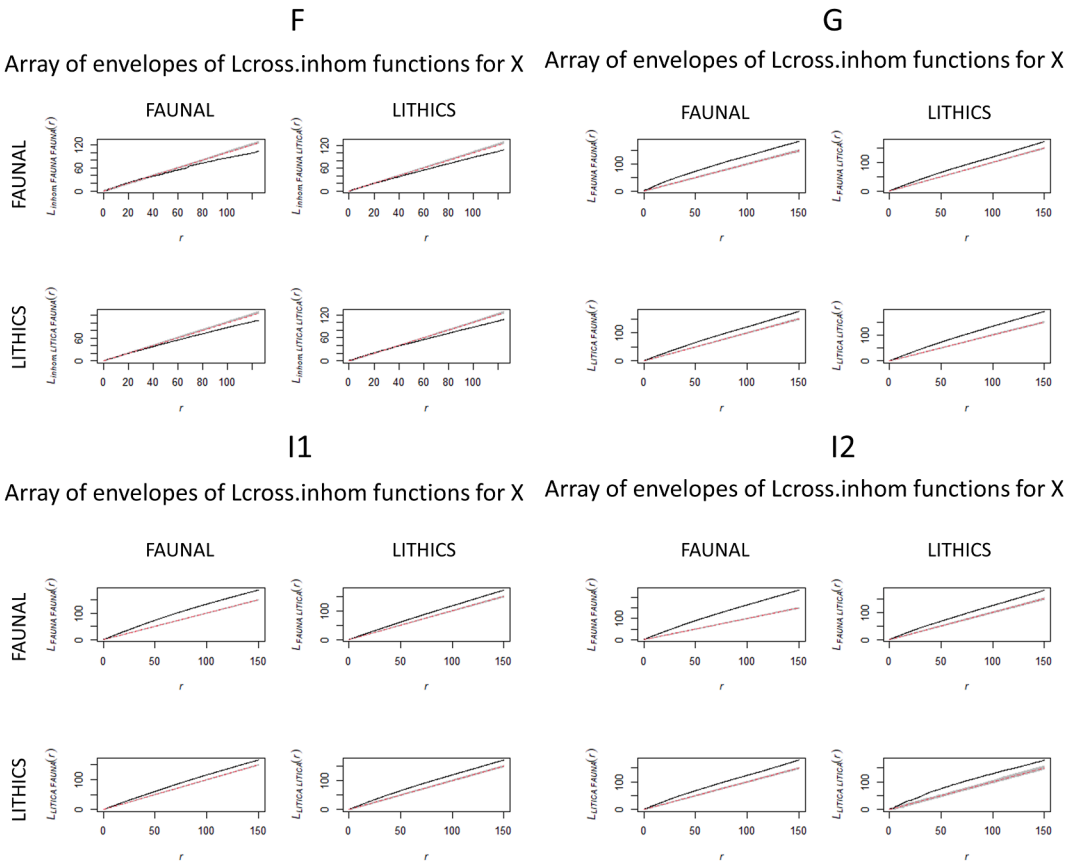

Figure 11. Inhomogeneous cross-type L function for faunal and lithic remains from Notarchirico levels F, G, I1, and I2. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

reveals the hominin presence in the area. Microwear analyses of tool edges indicate that these artifacts may have been used for processing several resources such as meat, plants, and wood (Moncel et al., 2020, 2023), suggesting that hominin groups foraged for most of the resources necessary for their subsistence in this landscape. Carnivore activity has been documented through modifications in the osteological assemblage, pointing to the presence of at least a large carnivore as a modifying agent. A distinctive feature of skeletal profile analysis is the notable absence of epiphyses in relation to shafts. It has been hypothesized that this absence at the Middle Pleistocene site of Qesem Cave is attributable to domestic activities associated with the processing of animal grease (Blasco et al., 2024) in the so-called '*home bases*' *or* '*residential camps*' described by Isaac (1971, 1978) as the places where they bring food and share it. Although there are certain differences and specificities, the faunal record of home bases in the European late Early and Middle Pleistocene reveals some main characteristics: (i) a high concentration of remains (NISP) and individuals (minimum number of individuals); (ii) a predominance of medium- and large-sized ungulates and a low representation of carnivore remains; (iii) a predominance of adult individuals; (iv) differential transport of carcasses, with a predominance of high-energy anatomical elements; (v) a frequent presence of anthropogenic modifications (cut marks, anthropogenic breakage, and, in some cases, signals of thermoalteration); and (vi) a large amount of evidence of butchering activities (Moigne and Barsky, 1999; Mania and Mania, 2005; Moncel et al., 2007, 2012; Blasco and Fernández-Peris, 2009; Barroso-Ruiz et al., 2011; Saladié et al., 2011; Blasco et al., 2013; Rodríguez-Hidalgo et al., 2015). In addition to the taphonomic evidence, the technological record of these assemblages should be considered. This is also characterized by a high concentration of remains, complete knapping sequences, and evidence of in situ knapping (Moigne and Barsky, 1999; Moncel et al., 2005, 2007, 2012; Ollé et al., 2013; Mosquera et al., 2018).

The evidence shown at Notarchirico does not suggest that this site was used as a home base. Notarchirico seems to correspond to a location where various predators, including the hominin groups, obtained different resources, and it is not possible to determine a main or leading actor in the formation of the assemblages. The various analyses based on skeletal profile ratios suggest highly competitive scenarios in the formation of the different levels, probably as a consequence of the availability of animal resources for several predators, as well as other resources such as fresh water, vegetable, or raw material for knapping tools (Egeland, 2008, 2014). This is consistent with the inferences described in other Middle Pleistocene sites, such as Isernia La Pineta (Pineda et al., 2020) or Torralba (Pineda and Saladié, 2019), as well as in the Early Pleistocene sites of Oldupai Gorge (i.e., Domínguez-Rodrigo and Organista, 2007; Egeland, 2008; Akuku et al., 2022) and Barranc de la Boella (Pineda et al., 2017). These scenarios seem to be similar in the whole sequence of the site as the different faunal complexes described through the sequence of Notarchirico (Mecozzi et al., 2024b) seem to correspond with a moment of abundance of resources, typically of the MIS 17–MIS 15 span of time. However, caution should be exercised when interpreting data from higher levels due to their fragmentary nature and the methodological limitations of the earlier excavations.

The absence of evidence for the co-occurrence of hominins and carnivores on carcasses appoints that both agents acted independently, exploiting resources of interest for their subsistence. Beyond this, it is evident that hominins intensively exploited the Venosa Basin, obtaining the resources necessary for their survival in the region for at least 100–150 ka, as indicated by the current data from Notarchirico in conjunction with the aforementioned inferences from the neighboring site of Loreto (Pineda et al., 2025). It is evident that in such a volcanic environment, characterized by a high concentration of predators and abundant wildlife, and with a long-standing geological history, the prevalence of single episodes can be attributed to numerous factors influencing its formation, modification, and reduction.

A recurrent pattern in the archaeological record since the earliest hominin paleolandscapes is the preference for open settings associated with accessible watercourses. Examples include early sites in North Africa such as Ain Boucherit (Sahnouni et al., 2018; Cáceres et al., 2023), Ain Hanech (Sahnouni et al., 2013), and El Kherba (Sahnouni et al., 2017), which represent the earliest evidence of occupation in the northern part of the continent. These sites exhibit clear signals of anthropic presence, including stone tools and evidence of carcass exploitation through cut-marked bones and, at Ain Hanech, also through microwear studies. Similar parallels are found in East Africa at sites such as Gona (Domínguez-Rodrigo et al., 2005) and, perhaps most paradigmatically, several localities from beds I and II of Olduvai Gorge, such as FLKN 1-2, FLKN 3, and FLKNN 3 (see Domínguez-Rodrigo et al., 2007; Egeland, 2008). Although the role of hominins as accumulating agents has been debated, they are described as part of a landscape that provided the necessary resources for their survival, in an interpretation similar to the one we propose for Notarchirico in this study. There are also examples in the European archaeological record, such as the Early Pleistocene sites of Barranc de la Boella, where the exploitation of faunal resources has been documented at one of the localities (Mosquera et al., 2015). However, the role of hominins in the accumulation of the different assemblages appears to be less intense (Pineda et al., 2017). Similar patterns can be observed in the Middle Pleistocene at sites such as Ambrona (Moclán, 2023) and, in closer chronological and geographical proximity, at Isernia La Pineta. Initial taphonomic studies at this site highlighted a significant role of hominins in the formation and modification of the faunal assemblages (Thun-Hohenstein et al., 2002, 2009), although later revisions also challenge these interpretations (Pineda et al., 2020), outlining a scenario similar to that described for Notarchirico. Understanding what occurred in open-air contexts is essential to complement and refine current knowledge of subsistence strategies as these sites often represent foraging and transit areas for Middle Pleistocene hominins and thus landscapes that were likely exploited and managed. This results in assemblages where the hominin role, though marginal, is key to understanding foraging and mobility patterns across macroregional spaces in their daily life.

Future reassessments of Early and Middle Pleistocene assemblages from the Italian Peninsula will be essential for refining our understanding of human paleoecology, particularly in relation to subsistence strategies, landscape use, and site formation processes in these contexts. Notarchirico joins the list of open-air sites that reflect transit areas of Pleistocene hominin groups, where they occasionally and repeatedly leave traces of their activity, which blend with other agents and processes.

6. Conclusions

Notarchirico is a Middle Pleistocene open-air site dated between 695 and 615 ka and developed within a fluviodeltaic sedimentary environment. It stands as one of the key locations for investigating hominin behavior in such landscapes, both in the Italian Peninsula and Western Europe. This site emerged within a complex ecological mosaic where a combination of open, semi-open, riparian, and aquatic habitats coexisted, providing various resources that supported the survival of different paleocommunities. This includes hominins, whose presence is directly attested by a femur of *H. heidelbergensis* recovered at the top of the sequence and by an abundant lithic assemblage distributed throughout the sequence. However, the relationship between hominin groups and the faunal remains is unclear as surface preservation is poor and there is virtually no evidence of anthropic exploitation of carcasses, especially now that the so-called '*elephant butchery area*' does not seem to correspond to an actual event of human exploitation. Carnivores also appear to have interacted with the assemblage, though they did not play a dominant role; rather, similarly to hominin groups, they likely accessed the area in search of resources. The spatial analyses we have applied to the assemblages also suggest that low-intensity water flows may have contributed to modifying the osteological assemblages, indicating that the site's taphonomic history could be complex. Despite the preservation issues affecting bone surfaces, which hinder some behavioral inferences, there is no doubt that hominin groups inhabited the Venosa Basin for approximately 100 ka between MIS 17 and MIS 15. Like various animal communities, they relied on this environment as a resource-rich landscape that provided the necessary conditions for their survival. In this context, Notarchirico stands out as a key site for understanding hominin adaptation and interaction with the Pleistocene ecosystems of Western Europe.

Declaration of competing interest

The authors state that there is no conflict of interest.

Acknowledgments

We thank the Soprintendenza of Basilicata (Italy) for according the research permission and for their scientific support, especially Dott.ssa T.E. Cinquantaquattro, Dott. F. Canestrini, Dott.ssa. R. Pirraglia, and Dott.ssa. S. Mutino, and Dott.ssa F. Carinci. We also thank Dott. A. Mantrisi of the Venosa Museum and the city of Venosa and the mayor. We would like to thank Dott.ssa Rosanna Calabrese and the Museo Archaeologico Nazionale; Marco Torelli; (Venosa, Basilicata) for access and logistical support. We would like to thank Director Dott. T. Serafini, the Italian Ministry of Culture and the Museo e Parchi Archeologici di Melfi e Venosa. Fieldwork was carried out with the financial and scientific support of the Leakey Foundation ('Early Evidence of Acheulean bifacial technology in Europe' grant, 2015–2016 and 2019–2021), the National Museum of Natural History, Paris, France (ATM Action Transversale du Muséum, 2016–2018), and the European Research Council-Adv. LATEUROPE n°101052653. A.P., M.C., and the analyses were supported by the LATEUROPE project (Grant agreement ID 101052653) that has received funding from the European Research Council under the European Union's HORIZON1.1 research program. B.M. is supported by Sapienza, University of Rome 'Progetti per Avvio alla Ricerca—Tipo 2 anno 2022' (Grant no: AR222181333C1B88) and 'Regione Lazio—Contributi premiali per i ricercatori e assegnisti di ricerca per rafforzarne la condizione professionale e potenziare il sistema della ricerca del Lazio' call proposal of the Lazio Region (DE G05411 del May 05, 2022). A.I. was supported by a Humboldt Research Fellowship provided by the Alexander von Humboldt Foundation. R.S. was supported by the Grandi Scavi 2019 (Grant no: SA11916B513E7C4B, Sapienza

University of Rome); Grandi Scavi 2020 (Grant no: SA120172B2C05E68, Sapienza University of Rome), Grandi Scavi 2021 (Grant no: SA12117A87BC3F0A), and Grandi Scavi 2022 (Grant no: SA1221816893E2AB). A.I. and R.S. were supported by the Italian Ministry of University and Research, PRIN 2022 scorrimento—Prot. 2022JWFEKE. The Institut Català de Paleoecologia Humana I Evolució Social (IPHES-CERCA) has received financial support through the 'María de Maeztu' program for Units of Excellence (CEX2024-01485-M/funded by Ministerio de Ciencia, Innovación y Universidades/Agencia Española de Investigación/ 10.13039/501100011033).

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Supplementary Online Material

Supplementary Online Material related to this article can be found at https://doi.org/10.1016/j.jhevol.2025.103789.

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